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DGPS in Aerial Spraying in Forestry: Demonstration and Testing

Final Report

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Executive Summary

The USDA Forest Service (FS) Forest Pest Management (FPM) conducted a demonstration and evaluation of differential GPS navigation equipment for use in aerial application of pesticides to FS lands. Typical FS needs are somewhat different than those of flatland agriculture and a demonstration/evaluation project was necessary to inform FS personnel of system capabilities, and to inform system manufacturers of FS needs, procedures and typical application environments. The program verified that the basic claims of the system manufacturers and distributors regarding system accuracy and potential for improving the state-of-the-art in FS applications are valid. However, some customization of these systems is needed and the full integration of these systems into forestry operations will require time and experience.

Acknowledgments

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Introduction

The rapidly growing use of Global Positioning System (GPS)-based navigation is impacting USDA-Forest Service (FS) Forest Pest Management (FPM) operations. This technology is based on the reception of signals from a constellation of satellites. These satellites were originally intended for military use, but the capabilities of civilian applications of GPS technology are increasing rapidly. Under optimal conditions, instrumentation using the signals from this satellite constellation can locate positions on the surface of the Earth with less than 2 m absolute error. A technology known as carrier phase differential GPS (DGPS) increases this accuracy to 2 cm. It is now the state of the art in surveying. Applications of this type of accurate positioning are numerous. Of great interest to FPM is the ability to accurately know and log to a stored file the exact position of an aerial or ground spray system during an application event. This ability can:

- Help eliminate the problem of treating the wrong area, consequently reducing the need for block marking.
- Provide aircraft tracking and guidance that allows the spray material to be applied more evenly.
- Yield detailed information for quality control, record keeping, and post-operational questions and challenges.
- Reduce the need for flaggers and associated safety and cost factors.
- Reduce or eliminate pilot time lost while finding home and when navigating to unfamiliar areas. Reduce costs associated with returning to base for reloading and returning to the exact position where application ceased.
- Improve the ability of the operational manager or applicator to immediately locate misses or gaps, allowing corrective action to be taken in a timely manner.

In general, costs can be lowered, safety improved, and efficiency increased when GPS navigation systems are integrated into FPM pesticide application operations (Thistle et al., 1994). Investigation and implementation of this technology has been noted as a priority by the USDA Forest Service, Forest Pest Management, National Spray Model and Application Technology Steering Committee, the National Steering Committee for Gypsy Moth and Eastern Defoliators, and other groups within the FS.

Forest Pest Management personnel needed to see this technology demonstrated and have the claims of the manufacturers and developers independently verified.

There were a number of operational uses of this technology by the FS and cooperative State aerial spray projects in the spring of 1994. The performance of the DGPS technology on these projects ranged from complete success to disappointment (nonperformance).

Operational personnel felt that it would be very useful to have a demonstration of the technology on a test course to let the private sector developers know what the FS needed and to answer remaining questions regarding the use of this technology in complex terrain. This approach would help to inform FS personnel of the capabilities of this technology as well as aid in integrating the technology into FS operations. Therefore, developers were invited to a demonstration and evaluation of DGPS navigation equipment suitable for use in FS aerial spray operations. The project was held on the Ninemile Ranger District west of Missoula, Montana, the week of October 9, 1994.

The DGPS aircraft navigation industry was canvassed to alert potential demonstrators. Two companies were willing to spend their own resources to come to Missoula and demonstrate equipment. The demonstrators were AgNav Systems of Swanton, Vermont, and Satloc, Inc., of Casa Grande, Arizona. These companies have invested substantial resources to enter the forestry DGPS aircraft guidance market. Both firms fielded impressive systems for this demonstration.

Technical Background

The U.S. Department of Defense (DOD) has been involved in building and deploying a constellation of satellites to be used in military operations over the past decade. The full constellation of 24 satellites was not deployed until 1994. Due to security concerns, DOD has opposed civilian use of the full system capabilities. Therefore, the DOD implemented a policy of selective availability (SA) where the signal is intentionally degraded. The GPS positioning available to the civilian community at large has an accuracy of better than 100 m (95% of the time) and 300 m (100% of the time) in horizontal positioning as opposed to 16 m available to the military. SA is achieved by purposely affecting the signal timing (dither) and satellite ephemeris (epsilon), which introduces a fluctuating error in the indicated position. Thus, using the raw GPS signal, a civilian recipient would not know exactly how far off of an absolute position the indicated position actually is at any given time.

The civilian community responded to SA by developing a differential system that eliminates the SA error and increases the positional accuracy to the 2-5 m level. This is accomplished by placing one receiver at a point of known location (called a base station). From the base station data, the range corrections necessary to make the receiver's determined location coincide with the known location of the point are calculated. These corrections are then applied to the coexistent data from other receivers (called rovers), producing accuracies of 2-5 m. This technique is known as differential GPS, and can be done in real time or as post-processing. Differential GPS is currently allowed by DOD and exceeds the accuracy available to the military. Navigation and guidance functions utilize the differential correction signal in real-time. GPS positional data can be post-processed to achieve DGPS accuracy if an archived differential correction signal for the time period in question is available.

Over the past 3 years, the GPS and DGPS technologies have begun to be used successfully by the agricultural aviation industry. The immediate cost savings and reduction in human exposure to pesticides realized by eliminating flaggers made this technology very attractive. Also, as environmental concerns increase, the ability to accurately control where application is performed and the ability to provide documentation based on automatically stored computer records in cases of legal challenges have proved important. The present state-of-the-art allows a differentially corrected GPS signal to be received at 5 Hz (5 cycles per second). This signal can be used to guide the pilot along a preprogrammed flight path (using audio or visual indicators), and can be stored with absolute accuracies greater than 5 m. It can be transmitted back to the ground and input as an overlay into geographic information systems (GIS), allowing an operations manager to observe the application in real time on a computer screen. The GIS capability is also valuable in analyzing coverage and efficiency as the record of the operation can be downloaded and input as a spatial overlay into the GIS database. Spatial summary statistics can then be calculated.

The current technology allows alarms to sound when the edge of a spray block is crossed and lights to turn on to indicate when a specific ground location is below the aircraft. The signals can be used in a control mode to perform spray on/off functions based on position. FPM is also investigating integration of the system with pseudo-real-time drift calculations and drift sensors to provide drift alarms. These alarms could alert applicators and operational managers to changes in field conditions that increase the risk of off-target drift of pesticides (Teske et al., 1994).

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A Review of Operational System Performance: Spring 1994

Differential GPS technology was used as a navigation aid and to yield a positional log in numerous operational insect suppression projects in Spring, 1994. The following is a summary of the performance of these systems in various programs as reported by FS personnel and cooperators. This list is organized by State and provides a reasonable sampling of system performance in the spring of 1994.

Arkansas

Plans called for a Trimble TrimFlight II system to be flown during gypsy moth suppression in Arkansas. Due to unavailability of TrimFlight II systems at this time, a T&L 2100 Avionics receiver was used. The project involved two Cessna AgTrucks and three Hiller-Soloy helicopters. One helicopter was replaced by a Bell 206 during the project. The systems were meant to be used as navigational aids in finding spray blocks, and then to set up appropriate point-to-point (A-B) lines. The systems used a differential station and a mobile ground-based repeater.

The system did not work on this project and the contractor was held in nonperformance. The system automatically went into a 'sleep' mode (unknown to the operator) and stopped recording. The problem was not overcome during the program, but indicated that the supplier had not properly tested and integrated system components before operational deployment of the system. (Ghent, personal communication, 1994).

Michigan

This GPS demonstration project was a cooperative effort by Oscoda County, Michigan Department of Agriculture, and USDA Forest Service. The aircraft were applying ***Bacillus thuringiensis*** (BT) in a gypsy moth suppression project (Haugen, personal communication, 1994).

This GPS project tested two types of DGPS units to see if they could be used to treat gypsy moth spray blocks in Michigan. One plane used the TrimFlight system by Trimble Navigation. The other plane used the AgNav system by Pestechcon, Inc. The installations in both aircraft consisted of a light bar installed at the top center of the instrument panel, and a LED screen unit (a moving map) with button controls positioned just below and to the right of the instrument panel. On both units the screen size was approximately 6 to 8 inches square.

Each plane was scheduled to spray 30 blocks: 10 blocks with conventional navigation (balloons only–but with DGPS data logging), 10 blocks with balloons and DGPS navigation, and 10 blocks with neither balloons nor DGPS navigation. Data from these blocks then could be compared to determine the accuracy of each method. However, numerous technical problems developed and the demonstration project could not be completed as designed. Here is a summary of the performance of each DGPS unit.

Trimble – Block coordinates were not transformed properly from the GIS system to the GPS system. The blocks generated by the GPS unit were about 60 miles from the actual targets. Thus, block corners were input during an initial "fly over" of each block, then the DGPS unit was used to fly the parallel swaths. This unit did not have a disk drive to download data. The computer box had to be removed from the plane to download the data.

AgNav – Initial problems of converting the GIS coordinates to a compatible format for this GPS unit were solved the day before spraying was scheduled. This unit provided excellent navigation to and within each block. However, inexperience with this unit and its methodology for data file storage resulted in the loss of all spray data.

The following are some of the comments made by the pilots:

- Better training should be offered by the companies along with better overall product support. Both pilots were on their own in installing and setting up the equipment. Neither company had hardware readily available, and both were late supplying it.

- Better manuals are needed. The units should be more "user friendly." They are hard to operate as you fly. One pilot guessed that he was spending 50% or more of his time looking at the unit inside the cockpit. The other agreed, but thought much of that time was needed because they were still learning. They felt that it was obvious that a "computer person" put the systems together rather than an "aircraft person." There was too much button pushing throughout the flight.

- One pilot thought a heads-up display would be best. One wanted a gimbal for the LED screen. Both agreed that the LED screens were hard to read at times and more contrast was needed.

- The TrimFlight unit gave the pilot a compass direction to fly to the new block, and keyed the light bar into that azimuth. The AgNav unit showed the aircraft initially situated at the bottom third of the screen. The aircraft moved along the screen in a direction (normally up) while the block was kept stationary.

- The TrimFlight unit displayed the number of acres completed at the end of each pass, and the percent completed. The AgNav unit allowed you to use a reset button if you started to spray a block and then decided to switch the direction of the spray swath because of changes in the wind.

- Both pilots wanted the light bar out on the nose of the aircraft rather than in the cockpit. They wondered why differential station frequencies couldn't be universal. They were both impressed with the accuracy of the units once they got them working.

AgNav has responded to these comments by pointing out that additional support was eliminated from this contract to keep costs down at the request of the applicators. Also, system documentation, user training, and user friendliness have been improved and emphasized since the Michigan tests.

North Carolina

Satloc AirStar DGPS systems were used in gypsy moth suppression programs in North Carolina. The aircraft used were two Turbo Thrushes and two Air Tractors (502 and 802). A light bar was mounted on the nose of the aircraft. No in-cockpit display screen was used. The performance of the system was satisfactory in this program. The main problem had to do with file naming conventions. Systems in different aircraft used the same file naming convention, which caused some confusion after the flights. (Ghent, personal communication, 1994).

The Animal and Plant Health Inspection Service (APHIS) was responsible for spraying sensitive areas in this program. An ARNAV R5000 GPS/Loran system, which did not utilize digital corrections, was used . The system used in this program did not include a data logger off the shelf. A data logger was subsequently linked to the system. This system did not update quickly enough in this application (Roland, personal communication, 1994).

Pennsylvania

Operational use of DGPS systems in aerial spray aircraft in Pennsylvania has been well documented. Mierzejewski et al. (1994) produced a comprehensive report that is recommended reading on this topic. It discusses three separate uses of this technology in gypsy moth suppression operations in Pennsylvania during 1994. Two programs involved the Satloc AirStar and one involved the AgNav system. The report discusses the advantages and deficiencies of these systems at that time. In general these programs were very successful. Complaints regarding the AirStar system involved certain software features and the in-cockpit positioning of the equipment. The AirStar system only allowed one block to be entered prior to aircraft departure. These concerns were addressed by Satloc.

The use of the AgNav system discussed by Mierzejewski et al. is discussed in further detail by Clymer (1994). The Clymer report describes a gypsy moth suppression program on the Allegheny National Forest. This program represented an unqualified success of this technology in FS applications. The technology saved substantial time and money. The AgNav systems were mounted in DC-3 aircraft that are flown with two crew members in the cockpit. This alleviated pilot workload concerns regarding unfamiliar procedures and instrumentation. The area sprayed consists of rolling hills, so differential signal reception was not a problem. A modem board failed during the operation, but this was quickly diagnosed and replaced. This program defined the potential of these systems. It indicated that in some circumstances, the off-the-shelf technology could yield spectacular results. It also indicates that some level of effort is justified to overcome remaining technical problems and to get this technology integrated into FS operations quickly.

Virginia

Differential GPS navigation technology was used in gypsy moth suppression work in the George Washington National Forest and Shenandoah National Park (Witcosky, personal communication, 1994). The system was assembled by Computer Systems Integration of Newport News, Virginia. It consisted of a Garmin Surveyor II GPS unit and a Motorola Palm Top computer. The system did not perform well. The poor performance is attributed to a lack of integration of system components. Persistent system noise made this setup almost unusable. This noise was variously attributed to connectors and insufficient shielding. Despite substantial effort by the system support personnel, the noise problem was not overcome during the program.

West Virginia

A brief report was received on gypsy moth suppression in West Virginia. The AgNav system was being used with DC-3 spray aircraft. The report indicates that the systems were performing well, though there was still some design work necessary to optimize it for gypsy moth suppression in the mountains. More user training would be helpful. (Adams, personal communication, 1994).

Wisconsin

Differential GPS technology was tested and used for guidance and logging on the gypsy moth eradication treatment program in Wisconsin (Clemens, personal communication, 1994). A Del-Norte Flying Flagman system in an AirTractor 300 aircraft was used on 5 of the 22 treatment blocks. The navigation system worked extremely well. Observers noted that spraying stayed on target and that flight lines were straight and evenly spaced.

The major limitation of the system was its inability to input polygons into the system. The system computed the flight lines based on a A-B (north-south) line. Therefore, treatment blocks could not be loaded into the system. The data logger functioned properly after some early malfunctions. The logged data was not easily converted to a GIS format file. Pilots were concerned that the placement of equipment in the cockpit needed to give more attention to pilot convenience.

Missoula Evaluation and Demonstration

Problem Definition and Objectives

Forest Pest Management recognizes two distinct sets of problems regarding GPS navigation technology. The first set involves technical concerns, the primary one being whether the signal can be reliably received by aircraft operating in mountainous or complex terrain. Global Positioning System navigation equipment is gaining wide acceptance among agricultural aviators. However, they typically work in relatively flat terrain. Much of the FPM application work is carried out under conditions where ground-based transmitters, which increase the accuracy of the system, would be obscured. Also, in extreme terrain, the aircraft would not 'view' enough satellites to resolve its position.

Another technical issue is that aerial applicators in complex terrain often fly curved paths instead of straight swaths. The curved paths are determined by the contours of the local terrain. This type of application requires a higher level of sophistication in the associated GPS software and control systems. Further technical concerns involve operator safety and pilot workload. With input from pilots and field evaluations, safety could be improved and workloads reduced compared to current operational methods.

The second set of problems involves the acceptance and integration of this technology into FS operations. Various field trials have demonstrated that this technology can provide the positional accuracy claimed for it (Mierzejewski 1993; Sampson 1993; Falkenberg et al. 1994). Beyond these technical questions, most of the technical concerns have been addressed. However, a critical part of this program is to demonstrate this technology, providing a clear rationale and justification (assuming the remaining technical issues can be adequately resolved) for FPM to implement GPS-based aircraft navigation.

The objectives of this program were:

- To identify and resolve the remaining major technical issues relating to the use of this technology in FPM operational environments.

- To transfer GPS technology into operations.

Demonstrator Notification

The Missoula Technology and Development Center (MTDC) began investigating DGPS navigation technology in 1991 when Tony Jasumback visited Casa Grande, Arizona, to view a demonstration conducted by Satloc, Inc. Since that time MTDC personnel have attended demonstrations or operational uses involving five different DGPS manufacturers. This allowed MTDC to become familiar with the major manufacturers of this equipment. MTDC also canvassed manufacturers/distributors of DGPS navigation equipment at the National Agricultural Aviation Association annual meeting in 1993. Four or five more companies were identified that had or were developing equipment for the forestry market. These companies were contacted directly and invited to participate in the program. Finally, MTDC advertised in the Consumer Business Daily (CBD) in an attempt to identify any companies that had been overlooked in the initial survey. Ten additional companies sent for information regarding these tests based on the CBD announcement.

Participants were invited to come to Missoula at no cost to the government. They supplied their own aircraft and were responsible for having the personnel and equipment on site to conduct the operation successfully. The Forest Service supplied a repeater aircraft, but participants were asked to supply and install the repeater themselves. Forest Service technician support was available when necessary. Participants also supplied the differential station equipment, although all surveying, including determination of base station position, was done in advance with the help of Don Patterson (USDA Forest Service Surveyor, Northern Region).

Test Plan

A test course has been developed to help answer the remaining engineering questions regarding the use of DGPS technology in aircraft guidance and positional data logging in complex terrain. Since a primary objective of this work was to demonstrate the technology to FS operational personnel, a consideration in laying out the test course was that most of it be visible from a single observation area. This objective was achieved and the only part of the course that was obscured from the view of the observers was a section of the course that was designed to cause the aircraft to lose line of sight with the differential station.

Figure 1.–Computer generated, 3-D rendering of the Ninemile Valley, west of Missoula. Note the test blocks are white. The figure exaggerates vertical relief by a factor of two.

The test course consists of three blocks and one grassy runway, all in the Ninemile Creek drainage approximately 30 km west of Missoula, Montana. Figure 1 is a three-dimensional computer rendering of the Ninemile Drainage. The blocks consist of:

- One open pasture in the valley bottom (Block 1, 3,300 ft or 1,010 m ASL)
- One on a shelf approximately halfway up the ridge (Block 2, 4,200 ft or 1,280 m ASL) of approximately 43 acres
- One of approximately 8 acres near the ridge top (Block 3, 5,100 ft or 1,550 m ASL).

Block 2 includes an exclusion area of approximately 3 acres within its boundary.

The runway is in the valley bottom and is approximately 1 km in length. The pilots were asked to perform the runway tests first, Block 1 with DGPS second, Block 3 with DGPS third, Block 2 with DGPS fourth, and then finish by flying Block 1 without differential. All blocks are on the Alberton, Montana, U.S. Geological Survey (USGS) quadrangle on the southwest side of Ninemile Creek in the Ninemile valley (Figure 2).

The course was not meant to simulate an aerial spray operation. Instead, it was designed as a series of engineering tests, which were meant to challenge the systems. Since the primary objective of this program was the testing, it was necessary to perform the program near Missoula and MTDC where engineering expertise and general technical support could be brought quickly and inexpensively to bear on the program. At various times during the testing, there were 15 people from the MTDC staff in roles onsite as photographers, engineering observers, aviation support, and general logistical support. With aerial suppression occurring from the Wasatch Front to the Atlantic Coastal Plain, it is hard to define a typical scenario. Therefore, the basic system capabilities and limitations were stressed so that individual users could make determinations regarding the application of this technology to their specific situation.

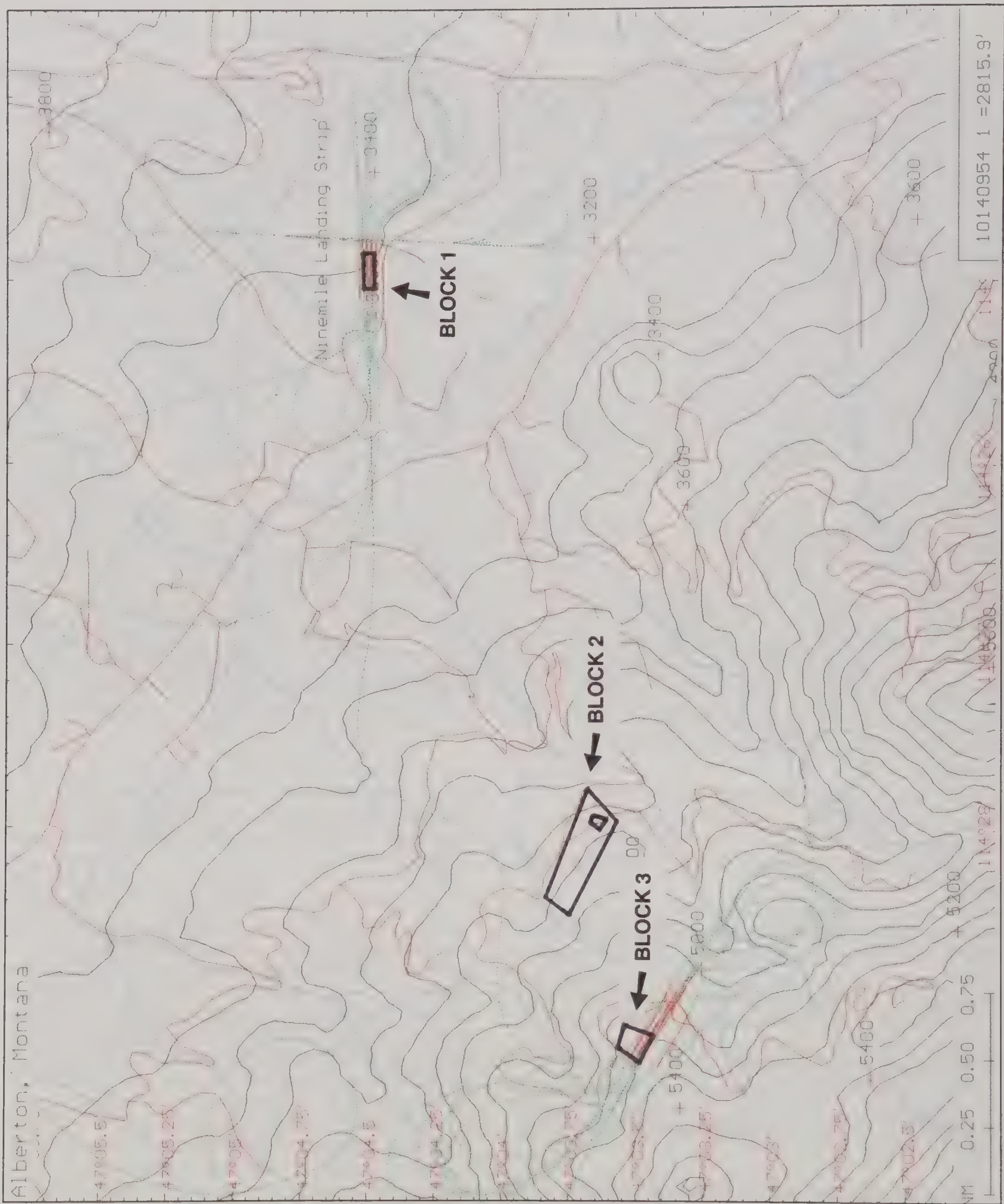

Figure 2.–Overall view of the test area with spray blocks (heavy black lines) overlying topographic contours (narrow black lines). This plot was generated by the Satloc AirStar system. The dotted green lines mark the flight path. Red lines over the test blocks show when the spray setting was on. Elsewhere, red lines are roads. Blue lines are stream drainages.

Test 1

The first exercise was intended to test the ability of a given DGPS system to accurately log the position of a straight line. This was accomplished using a surveyed runway center line (Figure 3) on the Ninemile District. The runway survey was performed with a survey-grade DGPS unit that utilizes carrier phase signal processing and is accurate to within a few centimeters. This was a straightforward test of the GPS system accuracy. Current DGPS aircraft guidance systems should be able to chart a line with accuracy approaching the ability of the pilot to fly a straight line. MTDC has deployed a meteorological tower near the runway to determine differences in wind conditions (both speed and direction) between trials (Figure 4). A video camera with time marking, placed at a known position, filmed the runway fly-by. The pilot was asked to fly the runway four times, alternating directions (twice in each direction).

Figure 3.–Grassy runway at the Ninemile Ranger District, looking north. A line was surveyed in on the left edge of the runway.

There was some debate as the course was being laid out (and subsequently) whether it was necessary to give the pilots the visual cues presented by the grassy runway. The camera at the end of the runway produced time-marked video of the runway fly-bys. The demonstrators were asked to produce the detailed positional log of the fly-by. The

Figure 4.–Meteorological monitoring was conducted so that conditions could be considered when comparing systems. Two monitoring stations were deployed. The one shown here was located near the runway in the valley bottom. A second tower was located at midlevel on the east face of the ridge.

correspondence of these two records demonstrates that the system is at the location indicated by the system instrumentation. There is merit in the argument that a random line would eliminate the question of visual cues, but the placement of the line on the runway led us to some important realizations regarding these systems. Also, considerations of safety and easy observation made the logistics of using the runway appealing.

Test 2

The second part of the quantitative trial involved flying test blocks. MTDC has established three test blocks in the Ninemile District. The blocks chosen contain some steep slopes and are typical of the local mountain terrain. The blocks were located using DGPS. The test evaluated the ability of the navigation system to fly to the blocks, record the path of the pilot during a hypothetical application and fly a straight-line return course. Swath width for all blocks is 50 ft.

The pilot first flew Block 1 in the valley bottom. This block is situated immediately adjacent to the observing station and is meant to involve the spectators. He then proceeded to the ridge top block (Block 3, Figure 5) in as direct a line as possible. This small block was meant to be a challenge for the system to find. Also, a portion of Block 3 was intentionally surveyed in behind a finger ridge to cause the aircraft to lose line of sight with the differential station.

In the middle of flying Block 3, the pilot was to break off and return to the valley bottom plot, buzz Block 1, and return to Block 3 and resume flying as close to where he broke off as possible. This was meant to test the home return features of the systems and to determine the system's ability to return to the same point in a block. A camera with time marking was positioned on Block 3 to independently verify the on-board system.

After completing Block 3, the pilot flew to Block 2, which is in the middle of the ridge (Figure 6) and flew that block, which includes a small exclusion area. This was meant to determine whether these systems can reliably be used to stop spraying over small sensitive areas. After completing Block 2, the pilot was requested to return to Block 1 and refly that block without differential correction. A camera was also positioned on Block 2 for independent verification.

Figure 5.–A view of Block 3, which was the ridge top block.

Figure 6.–A view of Block 2, which was the midlevel block, and included an exclusion area at the south end of the block.

Participants and Systems

Two systems were demonstrated during the week of October 9, 1994. The two systems demonstrated were the Satloc (Casa Grande, Arizona) system flown by John Goodwin of Custom Farm Service (Stanfield, Arizona) and the AgNav system (Pestechon, Swanton, Vermont) flown by Art Robinson of Forest Pest Management Institute (Sault Ste. Marie, Ontario, Canada) (Figure 7). Appendix A is the list that was presented to potential demonstrators as system features that might be useful in FS aerial spraying operations. The demonstrators were not bound by this list but it provided them with guidance. They were also encouraged to demonstrate other features they thought might interest FS personnel.

The AgNav System

The AgNav GPS Guidance System typically consists of five on-board devices. The P101 AgNav computer with internal GPS, pilot indicator and track bar display, moving map display, UHF receiver, and Turbo Modem. The unit is run by a 5 Hz GPS engine and is designed to be operated as a differential GPS system in agricultural crop spraying. The software is driven from a menu that can be used to select a preprogrammed area or enter a new area. Three modes are utilized:

- Map Mode - Used to display a map of the block, review coverage, and display spatial information such as area and location of the area.
- Grid Mode - Used during the application for guidance. Parallel swaths are laid out for the pilot to follow. The display automatically rotates when the aircraft turns.
- Way Points Mode - Used to calculate straight-line paths between two points. This can be used to navigate to and from blocks, etc.

The AgNav system (Figure 8) has been developed by Picodas Group, Inc., of Richmond Hill, Ontario. It uses a Novatel card as the GPS engine. This card yields positional information at 5 Hz. The 5 Hz information is used by the AgNav system in applications such as edge crossings where 1 Hz information introduces unacceptable errors when factored against flight speed.

Figure 7.–The AgNav DGPS system installed in a Cessna AgTruck.

Figure 8.–The Cessna AgTruck, flown by Art Robinson of the Forest Pest Management Institute during the Missoula program.

The REMSPEC option offered for the AgNav system gives the ability to analyze the spray. Output includes spray line detail and spray block summaries on such variables as aircraft height, boom pressure, rotary atomizer rpm, flow, application rate, temperature and relative humidity.

The Satloc System

Satloc, Inc., is based in Casa Grande, Arizona. The system consisted of a ForestStar-equipped Satloc AirStar System. The system components consisted of a 486 computer with a 12-channel GPS receiver, one 4-megabyte PCMCIA card, a power converter and differential radio receiver, one multifunction light bar, one in-cockpit display and keypad, and a 1/4 wave differential antenna, and a GPS antenna. The system was flown in an Ayres Turbo Thrush (dual cockpit, Figures 9 and 10) powered by a Pratt and Whitney PT6-34A Turbo-Prop (750 SHP).

Additional, optional equipment employed during these tests consisted of a heads-up display and a laser altimeter. The heads-up display consists of a CRT and lens unit that projects the image onto the windshield and control, voltage and electronics components. Also, real-time tracking software was demonstrated using the Alberton, Montana, USGS quadrangle map.

A 935.200 MHz portable differential base station consisted of a GPS 10-channel receiver, one differential radio transmitter, one 30 W signal amplifier, one palmtop computer, antenna, and a 12 V power supply.

The system uses the same Novatel card as the GPS engine that is used in the AgNav system. The Satloc system reduces data to 1 Hz for some system applications. The software has many options for setting up and configuring the system. There are five primary modes in which to operate the in-cockpit display. These are:

- Swath - Used to set-up parallel swaths, provide operational statistics (percent remaining, for instance), swath offset, etc.

- Navigation - Outputs exact position, ground speed, way point bearings, etc.

- Satellite - Standard satellite and constellation information and time since differential correction.

- The final two modes are programming modes that are used to alter system parameters and input data such as light bar increment, log speed, way point coordinates, etc.

Figure 9.–The Satloc DGPS system installed in a Turbo Thrush.

Figure 10.–The Turbo Thrush flown by John Goodwin of Custom Farm Service during the Missoula program (airborne) and the 206 repeater aircraft (foreground).

Results

Test Conditions

The first day of flying was October 12. The AgNav system was flown by Art Robinson in a Cessna AgTruck. Detailed meteorological data were lost this day due to a data logging error. However, the temperature was around 10°C with broken overcast and a high wind warning was posted at the National Weather Service office in Missoula. Strong winds were a factor in the testing at Block 3, which is near the crest of the ridge.

The second flying day was October 14. The Satloc system was flown by John Goodwin in a Turbo Thrush. Wind velocity at the valley bottom was <1.5 ms^{-1} and was <2.5 ms^{-1} at Block 2. The wind directions were SW and NW, respectively. Temperatures were around 4.5°C and humidity was over 90%. The day was characterized by a heavy overcast and occasional downpours. It was fortuitous that any flying was done that day. Scud hanging near the side of the ridge prevented flying Block 2.

The AgNav system was flown again on October 17 with light winds (<1.5 ms^{-1}) with light overcast and temperatures around 8°C. On this day, only the runway was flown and weather was not a factor.

The AgNav System

The AgNav system performed well overall. The technical personnel who put on the demonstration showed confidence in the system, had substantial experience with forestry operations and participated vigorously in the roundtable discussions. One aspect of the AgNav system praised by the audience was the statistical summary sheet that the system outputs with information presented in a straightforward tabular format vs. time.

Test 1 immediately indicated that there had been an input error in the setup of the AgNav system. Despite the intended purpose of the testing, when the guidance in the aircraft indicated that the test line was off the runway, the pilot decided to fly the runway visually. To the credit of the AgNav group, they were using an over-the-shoulder camera in the cockpit and the unedited film was shown to the observers within 2 hours of the flight. The film showed that the light bar was buried to one side or the other, depending on the direction of the pass. It was realized that the system was guiding the pilot to a different line. Although troubleshooting the system was complicated by the logistics and tight schedule of the test week, it was immediately suspected that the datum had been incorrectly entered into the AgNav system. Subsequent analysis of the data confirmed this suspicion.

The AgNav system had been programmed with the wrong datum (see Appendix B for a discussion of datums). The points that were given to the participants had been surveyed in using the WGS84 datum. The AgNav system had been programmed to interpret these points in NAD27. WGS84 is based on 1984 mapping technology and differs from the NAD27 (1927) datum by about 70 m on the ground at the latitude and longitude of Missoula. Since many maps are still in NAD27 coordinates, the system gives a choice of datums. The system had used NAD27 on a previous project and had not been reset. This datum shift could result in project failure if not detected because the points in the system will not translate to the intended points on the ground. This is an example of human error in the use of this technology and is not an indictment of the system beyond the fact that it would have been helpful to have the datum more prominently displayed so the error could have been detected and corrected more quickly. AgNav has said it will make this change.

In many respects this problem indicated that the system did work. The lightbar functioned as it was programmed to do, indicating the off-track error. Though a correction back to 1 m accuracy was not attempted, subsequent analysis was able to compensate for this error using standard surveying conversions between the two datums. This problem did lead to the realization that it is necessary to independently verify system position. It also pointed out the tendency for aviators to rely on visual cues, especially when flying near the ground.

The exclusion test (Block 2) was only flown by the AgNav system due to weather considerations on the Satloc test day. The AgNav system performed well and indicated the shape of the exclusion correctly. An aircraft speed of 120 mph converts to 176 ft/s (54.2 m/s). This is the distance that the aircraft covers between positional data if position is checked at 1 Hz. Considering that a square acre plot is approximately 209 ft (64.3 m) on a side, a 1 Hz system cannot resolve an acre plot. The positional data are available at 5 Hz from the Novatel card (higher frequency cards are now available) and the actual frequency the data are used becomes a system design and programming decision. At 5 Hz, the aircraft moving at 120 mph covers 35 ft/s (11 m/s) between data points. These considerations are critical in the development of buffer zones around small exclusion areas. The AgNav system demonstrated that small blocks can be correctly delineated and therefore sprayed around. Figure 11 shows the exclusion area with spray off indicated.

Location of Block 3, which was the most distant and smallest block, was achieved by the AgNav system. Block 3 was intended to cause the systems to lose the differential correction signal. Part of the block was behind a finger

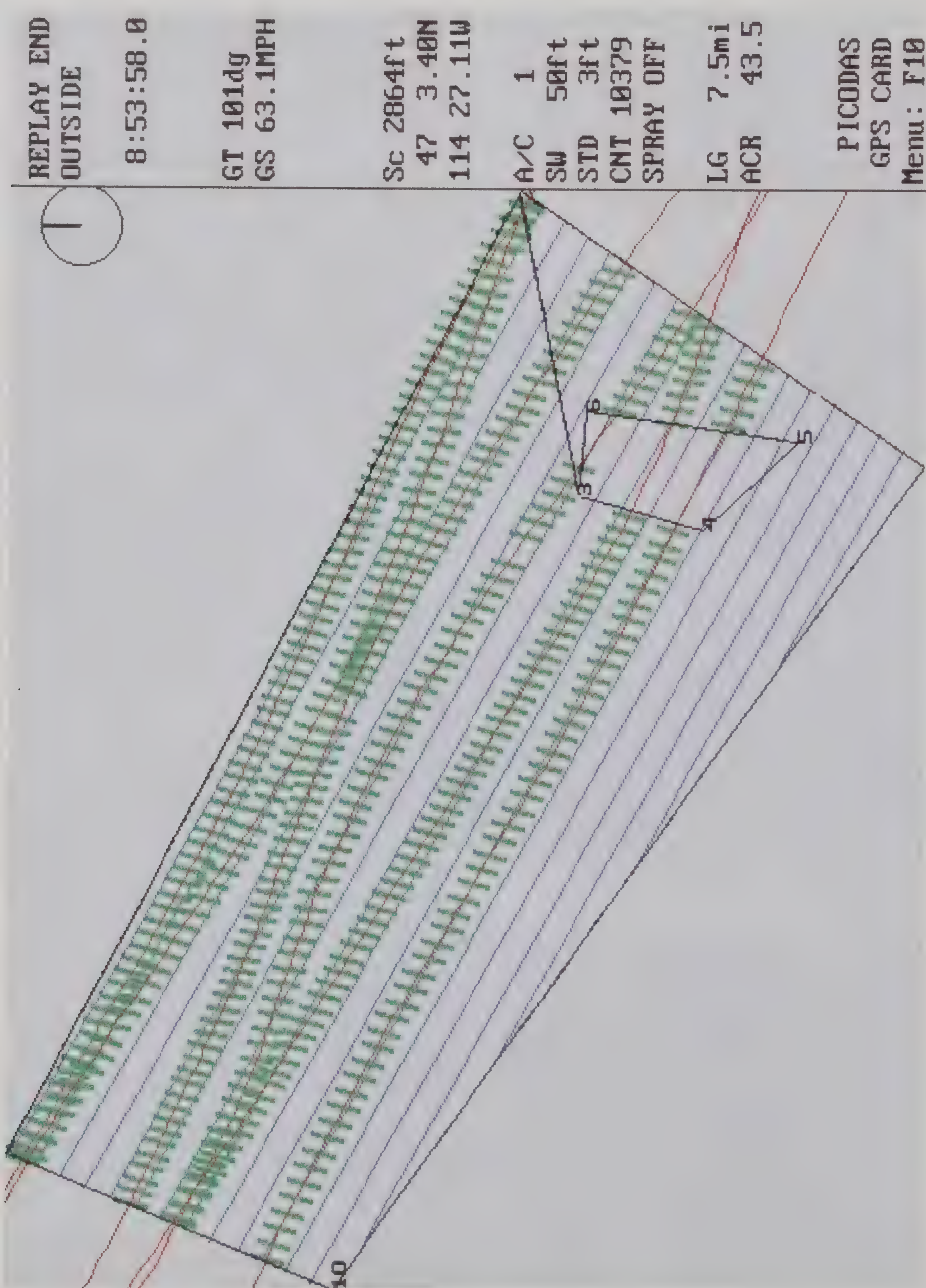

Figure 11.–Block 2 as generated by the AgNav graphics package. Note the small exclusion area. Black lines mark the block boundaries. Red lines are the actual flight lines. Blue lines are the calculated flight lines. Green lines mark the spray swath.

ridge that blocked the signal from the differential station. Due to tenuous flying conditions, the pilots could not fly low enough to lose line of sight. Block 3 demonstrated the limitations of the guidance aspect of these systems in complex terrain. The systems automatically calculate and display parallel lines as swathing guidance. This is not reasonable on an irregular small block with extremely steep slopes. Figure 12 shows the AgNav system flights on Block 3. The coverage is incomplete due to the pilot being uncomfortable with the high winds coming over the ridge. In this case, the graphic misrepresents the landscape by representing it as a two-dimensional area. It is recognized that this is not an operationally 'real' block, but instead was designed to point out limitations of these systems. See Appendix E for developments in curved path guidance for complex terrain flying.

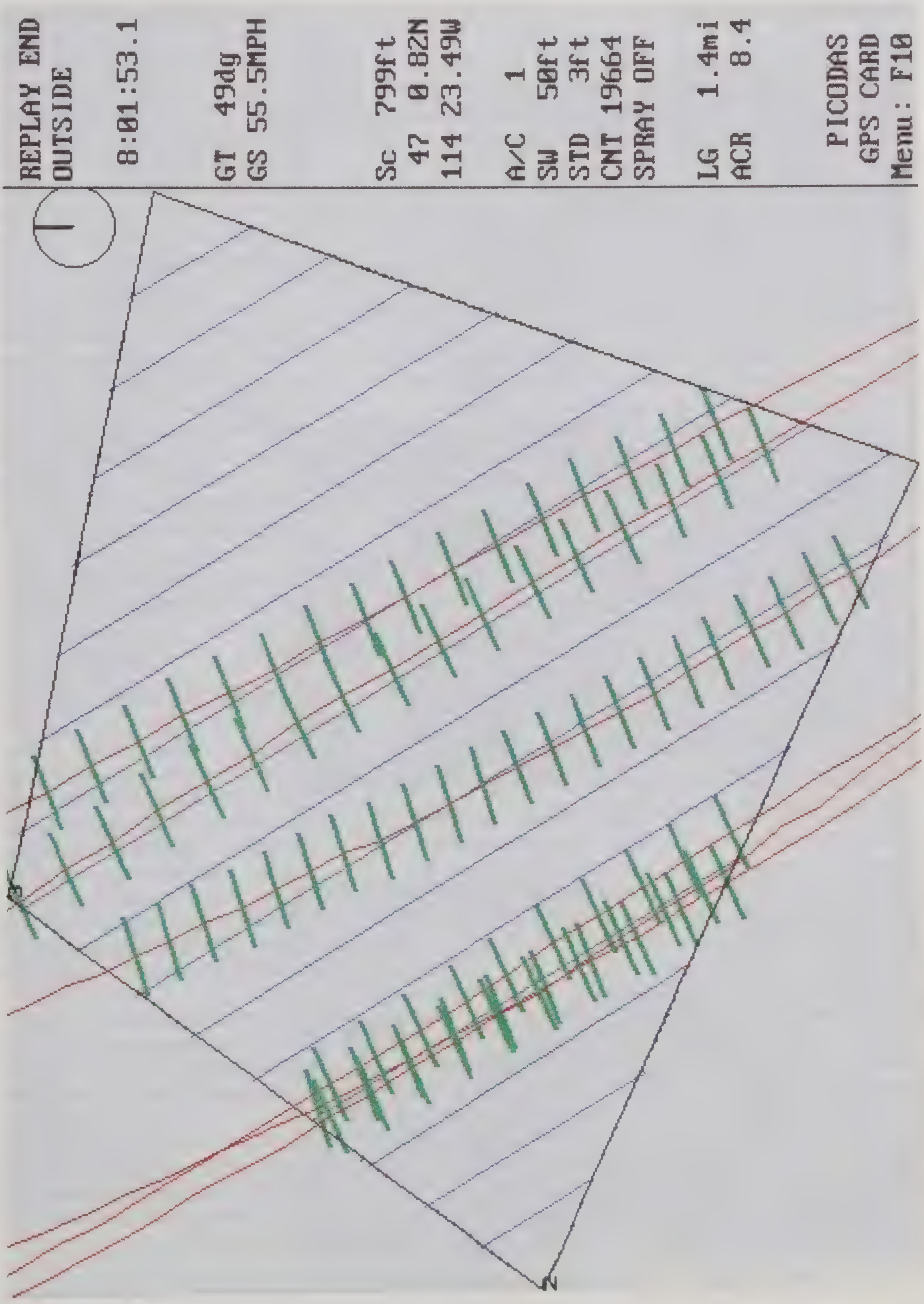

Figure 12.–Block 3 as generated by the AgNav graphics package. Black lines mark the block boundaries. Red lines are the actual flight lines. Blue lines are the calculated flight lines. Green lines mark the spray swath.

The Satloc System

The Satloc system performed well. Satloc supported the program with a technical staff that showed strong expertise in the deployment of these systems. The Satloc technical presentation was well received by the observers. The tests over the runway were performed successfully by Satloc. The pilot felt the runway was too strong a visual cue and this is substantiated by the above discussion. The data records of the Satloc passes offered more insight into these systems. The log file of position was compared geometrically to the straight line between the two surveyed end points. The two straight lines overlay with incredible precision (less than 1 ft or 0.3 m average absolute error). It should be noted that these two lines are not necessarily independent. The line used by the guidance system is the same line used in this calculation since the system had the two line endpoints (that had been surveyed in to an absolute accuracy of 2 cm using carrier phase equipment). Therefore, the system could calculate and output the same line that it is being compared with, regardless of system position.

The verification that the system was in the correct place was supplied by time-marked video footage. The camera position had been surveyed in and sighted down the known line. Though this technique does not offer independent verification of accuracy in the centimeter range, it does show deviations on the order of 1 or 2 m and can be synchronized exactly with the log file through the satellite clocks. The video record easily verifies that the system was within the 2 m accuracy claimed for it and that the logged record indicated position correctly.

Satloc did not fly Block 2 due to poor visibility. Therefore, it is impossible to verify that the system as currently configured could resolve the exclusion. Again, this would not be a fundamental limitation of the system since the system has positional information available to it at 5 Hz. If this capability is required on a project, it must be specified.

The pilot flying the Satloc system had difficulty using the onboard display. Satloc states in a post-test summary that this was due to a combination of a problem in the swathing display and the unfamiliarity of the pilot with some of the newer capabilities of the system. This problem led to the pilot having a difficult time turning spray on and off on the block edges while flying Block 3. This again points out the difficulty encountered in applying parallel swath guidance in rugged terrain.

Since Satloc was the second participant to fly, one adjustment was added to the program based on the AgNav experience. Satloc was asked to turn off the differential receiver while flying Block 1. Without the differential signal, the aircraft moved visibly off target laterally (the block edge was demarcated by a large tree). The Satloc system has the capability to log time since the last correction was received. This exercise emphasized the importance of the differential correction signal as accuracy is degraded from near 2 m with correction to as large as 300 m without it (see Technical Background).

Satloc demonstrated a real-time tracking capability that is quite impressive. The system showed the aircraft moving across a GIS overlay that was based on scanned-in USGS topographic maps of the surrounding area. The position of the aircraft was shown in near real time as it traversed the area. The block positions and the runway were entered on the map. The aircraft position in relation to the spray blocks could be monitored. This system was set up and operated under a canopy at the site providing near real-time, ground-based monitoring. Although this capability adds a level of cost and sophistication not necessary or desired on many operational projects, it offers new options to an operational manager for tracking and accountancy from a central point.

Repeater Aircraft

The Forest Service supplied a Cessna 206, piloted by Mary Verry of Missoula, Montana. This aircraft was intended to be used as a repeater aircraft during the trials. Originally, it was decided that the tests would not include a repeater. This was reconsidered because typical FS operations would include a repeater where differential correction is necessary and line of sight cannot be maintained between the aircraft and a differential station. Thus, it was decided to utilize a repeater aircraft primarily so observers would be aware that this was often a component of the system.

The repeater aircraft was used extensively by Satloc during the real-time demonstration. The airborne repeater was used to repeat aircraft position back to the tracking computer on the ground. It worked well in this application.

Since line-of-sight contact with the differential station was not lost by either pilot while flying Block 3, the performance of an airborne repeater to repeat differential corrections in the mountains cannot be evaluated based on the outcome of this program.

Demonstration

One of the purposes of this evaluation and demonstration is to disseminate knowledge of DGPS aircraft guidance in the FS and the potential user community as a whole. Approximately 75 people observed some portion of this program, with over 50 people traveling into Missoula for it (Figure 13). Three countries were represented (United States, Canada, and New Zealand), several Federal and State agencies (FS, APHIS, Air Force, to name a few, Figure 14) as well as a strong representation from State governments and the private sector.

Figure 13. The observation trailer in the Ninemile Valley.

The test course was designed with observers in mind as almost the entire course could be observed from the grassy airstrip in Ninemile Valley. A trailer was set up for observers. The weather was marginal and this negatively impacted the ability of the observers to see the flights (as well as keeping them cold and wet, on occasion). A program of sit-down technical discussions accompanied the actual flying and these sessions generated some very profitable interactions (see Appendices). Half of a day was spent in the field providing the participants hands-on experience with handheld GPS, differential technology, survey grade GPS and drift alarm systems (Drift Sentry, Courtesy of B. W. Jorden & Co., Inc.).

Figure 14.–A contingent from the U.S. Air Force observes the Missoula program.

The comments from the observers were positive and indicated that the discussions, tests, and demonstrations were informative. The observers were encouraged to interact with the demonstrators. Both demonstrators made their aircraft available for inspection on the ground (Figure 15). Observers were encouraged to sit in the cockpit to get a feel for the ergonomics, visibility, and size of the two systems.

Figure 15.–Demonstrators took the opportunity to explain the systems in the field. John Goodwin (on wing) describes the Satloc system to observers.

The technical talks were conceived as informal filler sessions between flying. The number of observers increased and interest in the program grew. The technical session gained a life of its own as session moderators and speakers took the success of the session to heart. Certainly the information exchange was fast and furious.

Recommendations

Considering the performance of these systems during the Missoula testing, two basic recommendations are made for using these systems in FS work in the near future.

- A known point should be surveyed in on the site of the base of aerial operations. Most FS and State personnel have access to surveying expertise, though this can be effectively accomplished with a handheld GPS unit by storing a file and post-processing against archived differential corrections. Prior to the beginning of the operation, the plane should be parked over the known point. The reading from the DGPS navigation system should correspond to within 5 m of the surveyed point. If it does not, the source of the discrepancy should be identified and the discrepancy reconciled.

- A video camera should be positioned on a known landmark that also corresponds to a recognizable position in the spray operation (block edge, etc.). Since the GPS satellites transmit exact time, the face of a handheld GPS receiver showing satellite time should be filmed occasionally while the aircraft system is airborne nearby. A time-marked record should be requested from the airborne system. This simple groundproofing will allow a manager to verify the approximate location of the aircraft at a given time.

It is acknowledged that these recommendations are both cost items, but even with these safeguards, the DGPS navigation systems will still be cost effective. The recommended procedures will provide forestry managers with independent verification of aircraft position and system accuracy.

Conclusions

- The accuracy claims of the DGPS navigation systems are valid. The error in position when using DGPS technology is smaller than the sum of other positioning errors caused by spray drift, pilot skills, and knowledge of the exact location of the pest.

- It is important to obtain independent verification of system coordinates.

- Software that automatically calculates parallel flight lines and uses these as guidance flight lines may not be useful in complex terrain. Parallel flight lines might not be practical in aerial spraying in the mountains.

- Detailed training is critical to the correct use of the system by the pilot.

- The optimal use of these systems will involve an integration into (as opposed to a replacement of) current practices such as visual flight.

- Make certain the spatial resolution of the system matches the resolution required for successful completion of the application program. One Hz data may be suitable for most forestry applications, but not all.

- These systems do not prevent fraud or eliminate the need for observers. However, the number of observers needed is reduced.

In the demonstration portion of these tests, Satloc focused more on field demonstration while AgNav kept the test flying straightforward but gave a long sitdown presentation of system capabilities. The observers liked the AgNav output table, which gives the time history of the spraying. The engineers were impressed with the real-time tracking ability demonstrated by Satloc and the new possibilities that this capability presents.

Forestry operations in complex terrain present design challenges to the system developers. However, the business and engineering groups associated with the Satloc and AgNav systems have developed systems specifically to fill the forestry niche (other groups have expressed a verbal interest even though time, money, or the state of their product development caused them to decline participation in this program). The demonstrators showed considerable confidence in their respective systems and were willing to openly discuss difficulties and problems (even pointing them out in many cases). Expectations have been raised and what was considered difficult 3 years ago is no longer an impressive system capability. This technology is evolving rapidly and any evaluation of capabilities is effectively a snapshot in time. This program has indicated that groundproofing of these systems is prudent.

It is important that the USDA Forest Service understand and utilize this technology in aerial spraying. Differential GPS-based navigation and positional logging allow operational managers timely access to detailed, accurate information that was not available previously. This information allows the manager to achieve the goals of accurate placement of spray material and increased accountancy of spray material released to the environment.

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Thistle H. W.; Jasumback, A. E.; Kilroy, W. 1994. DGPS navigation systems for agricultural aircraft in forestry: test plan. Proj. Rep. 9534-2807. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center.

Appendix A–Equipment Capabilities

The desired equipment capabilities listed here are based on a previous list prepared by Tim Roland of APHIS. This list has been substantially altered to reflect program needs of FPM. The technology requested in this list is known to exist or is thought to be possible as hardware or software extensions to existing technology. The actual equipment used in Phase I was dependent on the outcome of the bid process for the operational spraying programs. Phase I is intended to focus attention on specific logistical concerns, including equipment problems, that will only become evident in an operational environment. Demonstrators considering participation in Phase II should consider the following system capabilities as features that are considered potentially useful in FPM applications.

- Provide real-time differential GPS guidance with 5 Hz update capabilities and a maximum absolute error of 2-5m. Higher spatial accuracy is desirable.

- Selectable application patterns with ability to use contours for complex terrain applications.

- Variable swath width.

- Data logging capabilities with sampling rates from the basic 5 Hz of the positional signal and lower. Full record includes position, time, altitude, speed, track, application on/off. File labels will include aircraft number, pilot and job name or number. Additional consideration will be given to systems that log wind speed and direction, temperature, relative humidity and flow and/or release rates of the applied material.

- Capability to log all defining elements of an application job or area.

- Pre-loaded route capabilities interfaced with a light bar for real-time pilot guidance.

- Edge indicators to alert pilot when he crosses into/out of specified area.

- Light bar must be easily visible with optical increments programmable down to 1m.

- A feature which provides instant range and bearing to home base port.

- A feature which allows applicator to return to exact point the application stopped.

- GPS Guidance System malfunction indicators.

- The capability to transmit real-time information (essential data elements from 4 and 8) to a second party on the ground.

- A GIS system integrated so that near real-time information can be displayed during operations at a ground station. This GIS system should be expandable and inclusion of new geographic data bases should be an user friendly and standardized procedure.

- An easy to read in-cockpit display will show swath number, cross track error, true ground speed, total acres sprayed, magnetic heading.

Appendix B–DGPS Technical Overview

1.2 GPS System Design

The GPS system design consists of three parts:

- The Space segment
- The Control segment
- The User segment

All these parts operate together to provide accurate three dimensional positioning, timing and velocity data to users worldwide.

1.2.1 THE SPACE SEGMENT

The space segment is composed of the NAVSTAR GPS Satellites. The final constellation of the system consists of 24 satellites in six 55° orbital planes, with four satellites in each plane. The orbit period of each satellite is approximately 12 hours at an altitude of 10,898 nautical miles. This provides a GPS receiver with six to ten satellites in view from any point on earth, at any particular time.

The GPS satellite signal identifies the satellite and provides the positioning, timing, ranging data, satellite status and the corrected ephemerides (orbit parameters) of the satellite to the users. The satellites can be identified either by the Space Vehicle Number (SVN) or the Pseudorandom Code Number (PRN). The PRN is used by the NovAtel GPSCard.

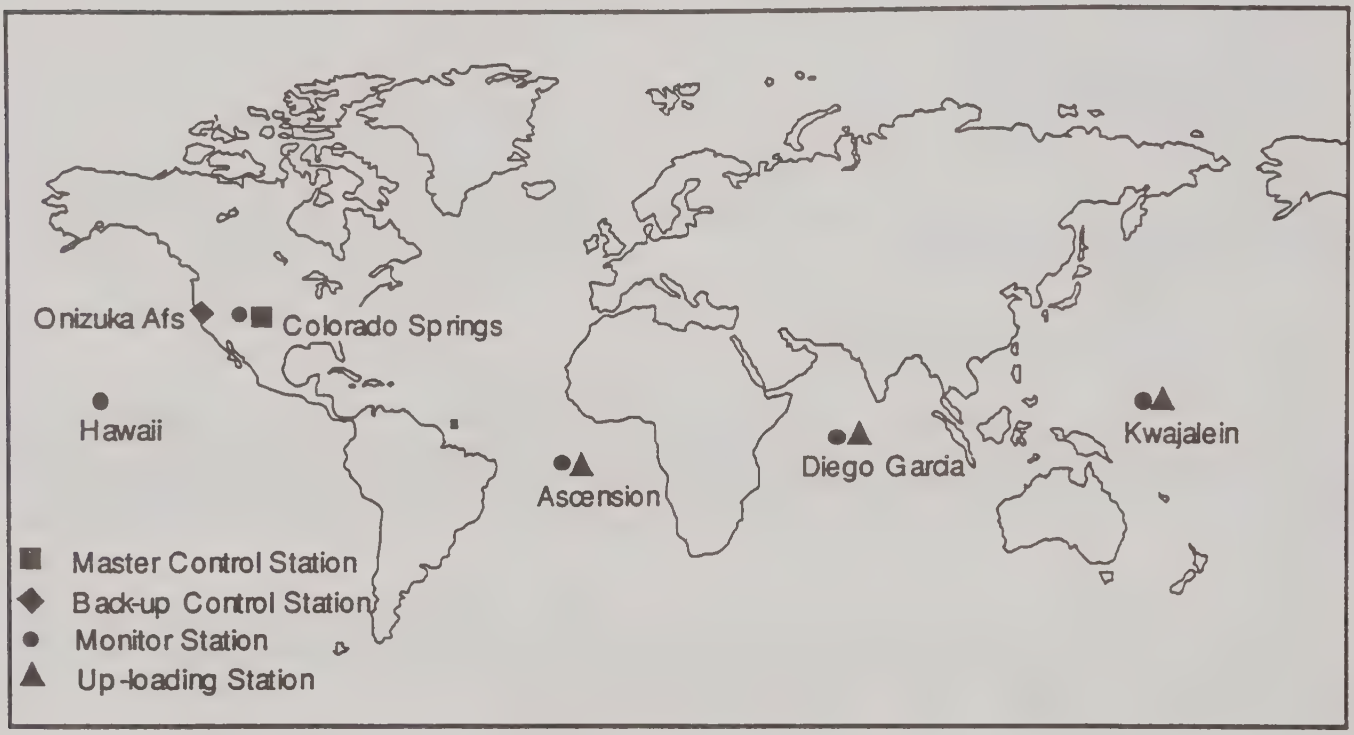
The GPS satellites transmit on two L-band frequencies centered on 1575.42 MHz (L1) and 1227.60 MHz (L2). The L1 carrier has a sequence superimposed on the carrier frequency by modulations in the forms of codes, a Precision (P) code and a Coarse/Acquisition (C/A) code. The L2 carrier contains only the P code which is encrypted for military and authorized users. The NovAtel GPSCard utilizes the L1 carrier and the C/A code.

1.2.2 THE CONTROL SEGMENT

The control segment consists of a master control station, five monitor stations and three data up-loading stations. Colorado Springs is the master control station and one of the five monitor stations. Hawaii is another one of the monitor stations whereas Ascension, Diego Garcia and Kwajalein are combined monitor and up-loading stations. See Figure 1-2 for their locations.

The monitor stations track and monitor the satellites via their broadcast signals. The broadcast signals contain the ephemeris data of the satellites, the ranging signals, the clock data and the almanac data. These signals are passed to the master control station where the ephemerides are re-computed. The resulting ephemerides corrections and timing corrections are transmitted back to the satellites via the data up-loading stations.

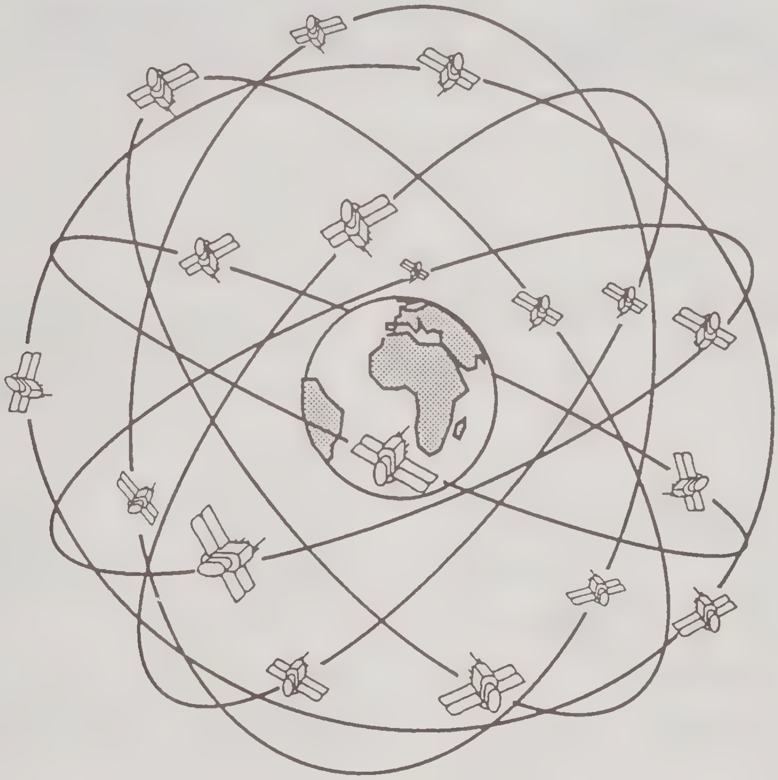
Figure 1-2 GPS Control Segment Locations



1.2.3 THE USER SEGMENT

The user segment, such as the NovAtel GPSCard receiver, consists of equipment which tracks and receives the satellite signals. The user equipment must be capable of processing the time and position information from a minimum of four satellites to obtain accurate position, velocity and timing measurements. A user can also use the data provided by the satellite signals to accomplish specific application requirements.

GPS CHARACTERISTICS



- 21 satellites + 3 active spares
- 6 orbital planes at 55°, 12-hour periods, 20,000 km$^+$ altitude
- Worldwide and continuous coverage
- Frequency and time synchronized signals
- L1 = 1575.42 MHz,   L2 = 1227.6 MHz
- ***Line-of-sight***, all-weather
- PRN C/A (L1) and P (L1 & L2) codes for pseudoranging
- Continuous navigation message
- Pseudo-ranging accuracy: 10 - 300cm (C/A), 10 - 30 cm (P)
- Carrier phase (ambiguous): $\leq$ 5 mm

GPS SINGLE POINT PERFORMANCE

Instant. Acc.			Selective Availability On	Off
SPS C/A 95% PDOP ≤3	Position	Horiz:	100 m	20 to 30 m
		Vert:	156 m	30 to 45 m
	Velocity		0.45 m s^{-1}	0.3 m s^{-1}
	Time		300 ns	40 ns
		SEP:	76 m	30 m
L1/L2 P code 95% PDOP ≤3 A.S. Off Civilian receiver	Position	Horiz:	100 m	15 to 25 m
		Vert:	156 m	20 to 30 m
	Velocity		0.45 m s^{-1}	0.1 m s^{-1}
	Time		300 ns	30 ns
		SEP:	72 m	16 m

A.S. Anti-Spoofing (P code shifted in time - Y code)

SEP: Spherical Error Probable (50%)

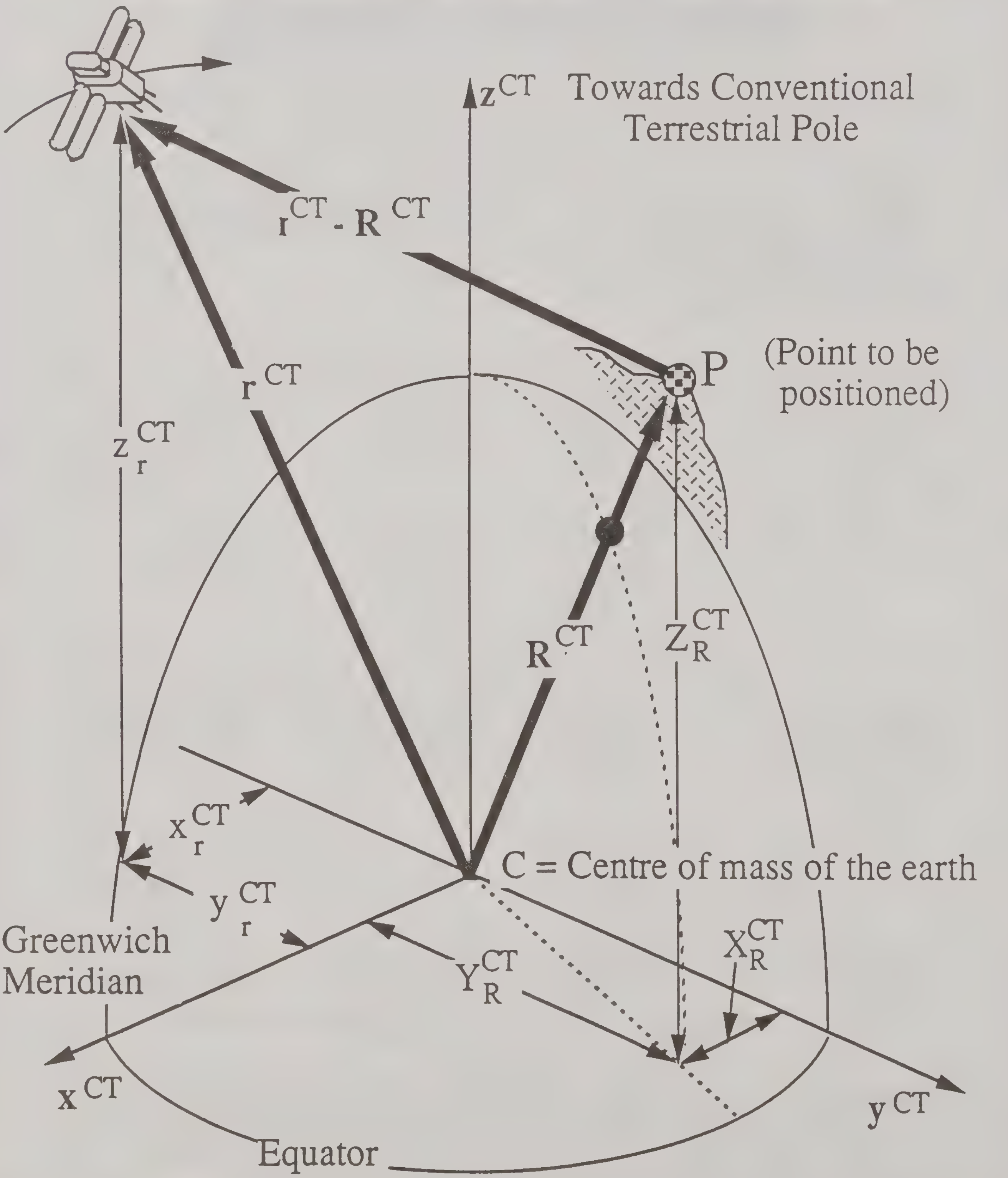
DGPS KINEMATIC POSITIONING PERFORMANCE

C/A Code [PDOP≤3]	Distance Monitor-Remote	Selective Availability	On	Off
			On	Off
Carrier Phase Smoothing[1]	10 km	Horiz:	1 to 3 m	1 to 2 m
		Vert:	1 to 4 m	2 to 3 m
	500 km	Horiz:	3 to 7 m	2 to 4 m
		Vert:	4 to 8 m	3 to 5 m
Carrier Phase Smoothing[2]	10 km	Horiz:	25 - 75 cm	20 - 50 cm
		Vert:	35 - 100 cm	30 - 75 cm
Carrier only[3]	10 km	Horiz:	1 to 5 cm	1 - 4 cm
		Vert:	2 to 6 cm	2 - 5 cm

1 Standard C/A code receivers [code measuring accuracy 1 - 2 m]
2 High Performance C/A code receivers with code measuing accuracy of 10 cm and high code multipath rejection capability
3 Carrier phase ambiguities solved with/without static initialization

CONVENTIONAL TERRESTRIAL COORDINATE SYSTEM

1.3



SELECTIVE AVAILABILITY AND ANTI-SPOOFING

SELECTIVE AVAILABILITY

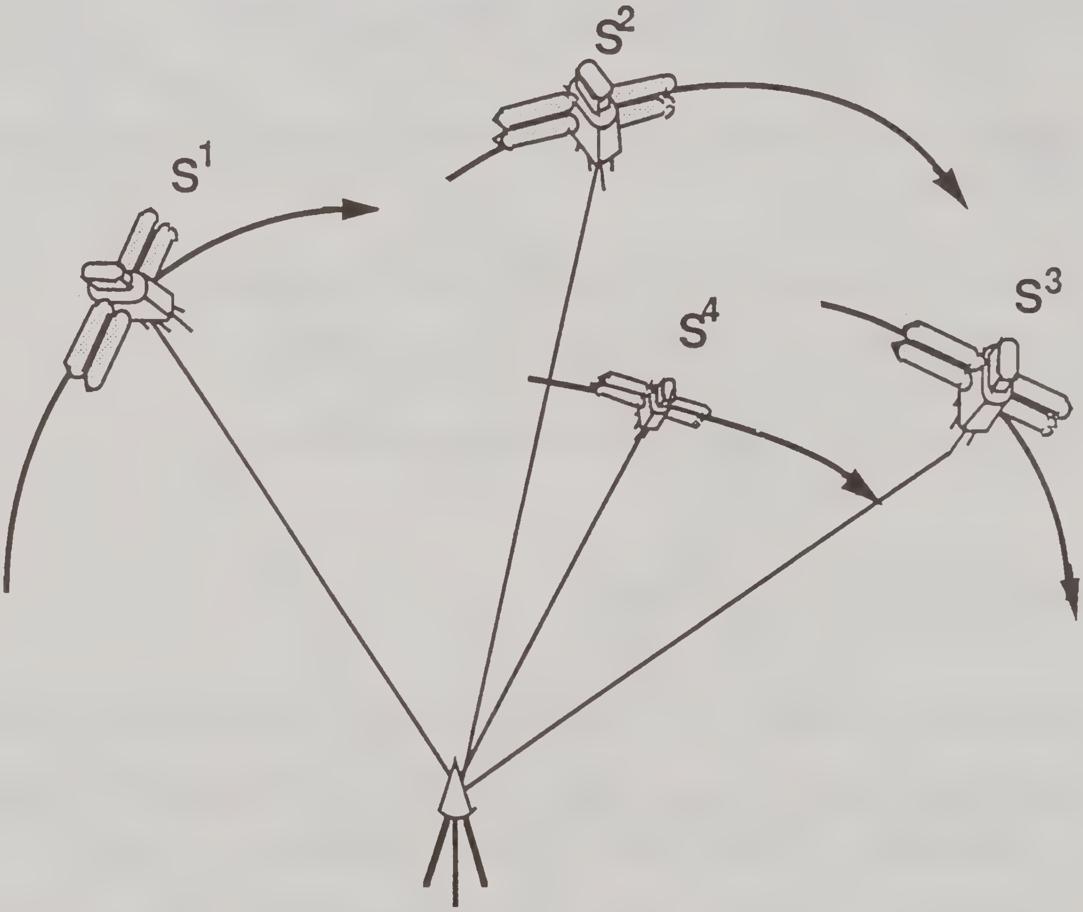
- Controls accuracy of GPS available to non-authorized users
- Effected through satellite clock dithering (δ) and broadcast orbit accuracy (ε) degradation
- Various S.A. levels can be implemented

ANTI-SPOOFING

- Prevents receivers from being spoofed by fake signals
- Effected through encryption of (long) P code (time shifting is sufficient). Encrypted P code becomes Y code
- P code on L1 and L2 no longer possible with standard code correlation techniques

Authorized receivers/users can receive cryptographic keys to overcome (undo) the effects of S.A. and A.S.

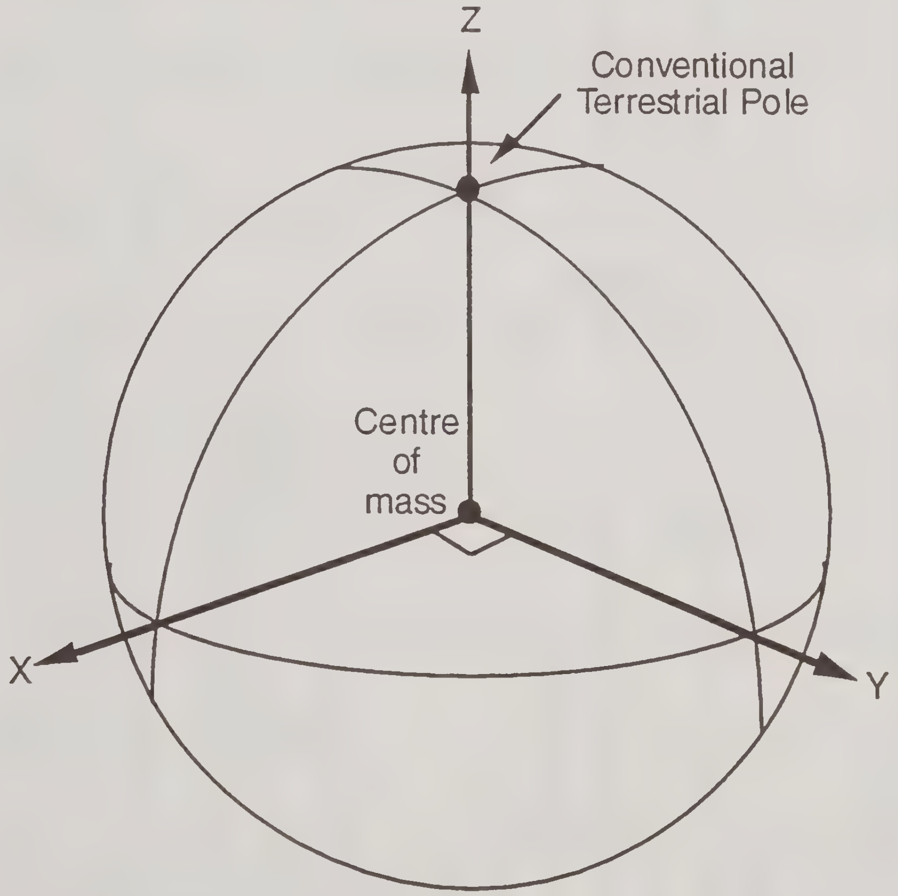
GPS RANGING CONCEPT: TRILATERATION IN SPACE



- Unknowns: f, l, h, cdt (cdt... receiver clock bias)
- {*Satellite clocks are synchronized to GPS time*}
- Minimum number of observations required for a 3D fix: 4
- Same concept as terrestrial trilateration, with 2 differences:
  - <u>Targets</u> (satellites)<u> are moving</u> (≈ 4 km per second)
  - As a result of above, the <u>geometry is changing</u> as a function of time

WGS - 84

- GPS has been using the World Geodetic System 1984 (WGS-84) as a reference since 1987 (WGS-72 previously)
- WGS-84 is a realization of a Conventional Terrestrial System (Z defined by CIO, X defined by Greenwich and Y to give a right-handed system)



Parameter and Value	Description
$a = 6378137$ m	semi-major axis
$J_2 = 1082630 \times 10^{-9}$	Zonal coefficient of second degree
$\omega_e = 7292115 \times 10^{-11}$ rad s^{-1}	Angular velocity of the earth
$\mu = 3986005 \times 10^{8}$ m^3 s^{-2}	Earth's gravitational constant

WGS 84

WGS 84 ELLIPSOID

Defining Parameters:

• semi-major axis	a	6 378 137 m
• 2nd degree harmonic coefficient	$\overline{C}_{2,0}$	$-484.166\,85 \times 10^{-6}$
• angular velocity	ω	$7.292\,115 \times 10^{-5}$ rad s^{-1}
• geocentric gravitational constant	GM	398 600.5 $km^3 s^{-2}$

Derived and Other Constants:

• untruncated angular velocity	ω'	$7.292\,115\,1467 \times 10^{-5}$ rad s^{-1}
• semi-minor axis	b	6 356 752.3142 m
• flattening	f	1 / 298.257 223 563

WGS 84 GRAVITY FIELD

180 x 180 gravity field - now unclasssified

WGS 84 COORDINATE SYSTEM

- Reference frame is the Conventional Terrestrial System as established by the BIH
- System realized by adopting WGS 84 coordinates for over 1500 Transit stations
- Relationship between Transit NSWC 9Z-2 system and WGS 84 is given by

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{WGS\,84} = \begin{bmatrix} 0 \\ 0 \\ -4.5\text{ m} \end{bmatrix} + (1 - 0.6 \times 10^{-6}) \begin{bmatrix} 1 & -0.814'' & 0 \\ 0.814'' & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{9Z-2}$$

GPS (WGS 1984) TO CONVENTIONAL DATUMS

(1) Three-parameter transformation (Δx, Δy, Δz) (shift)

- no distortion in local datum
- local datum as same orientation and scale as WGS84
- one set of (Δx, Δy, Δz) is sufficient for the entire datum

(2) 4- to 7-parameter transformation (shift, scale &rotation)

- no distortion in local datum, but
- scale and orientation differences w.r.t. WGS84

(3) Distortions in local datum (e.g., NAD27)

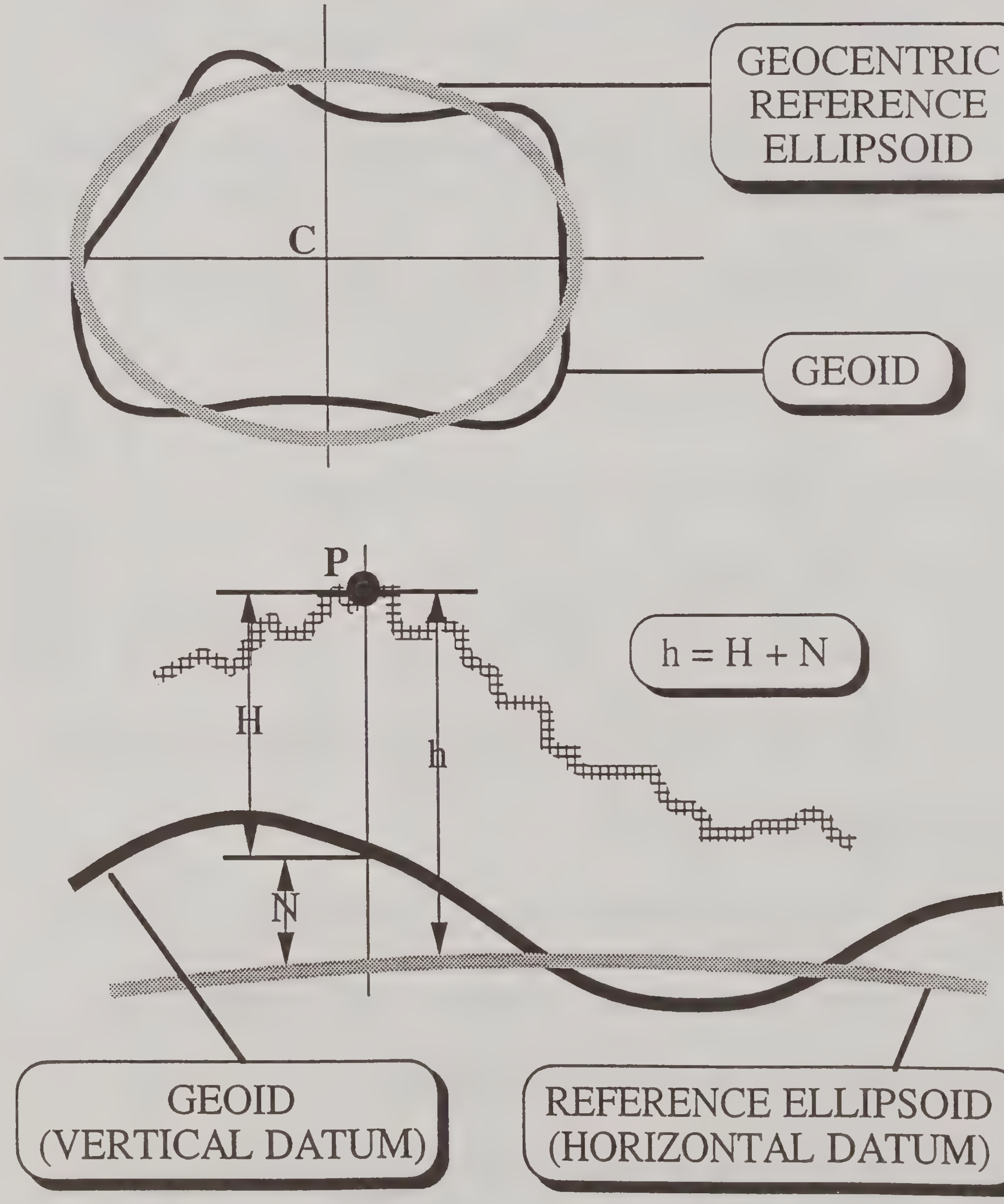
- several methods to transform
- use a regional three-parameter transformation (e.g., NAD27 [1, Appendix D] - not ideal - discontinuities may occur
- Use specified polynomials (e.g., NAD27 $\rightarrow$NAD83)

- **WGS84 TO NAD83**
  - $\Delta f = - 1,6 \times 10^{-11}$; $\Delta a = \Delta s = \Delta X = \Delta Y = \Delta Z = 0$
  - No rotation correction
  - In practice, NAD83 coincides with WGS84

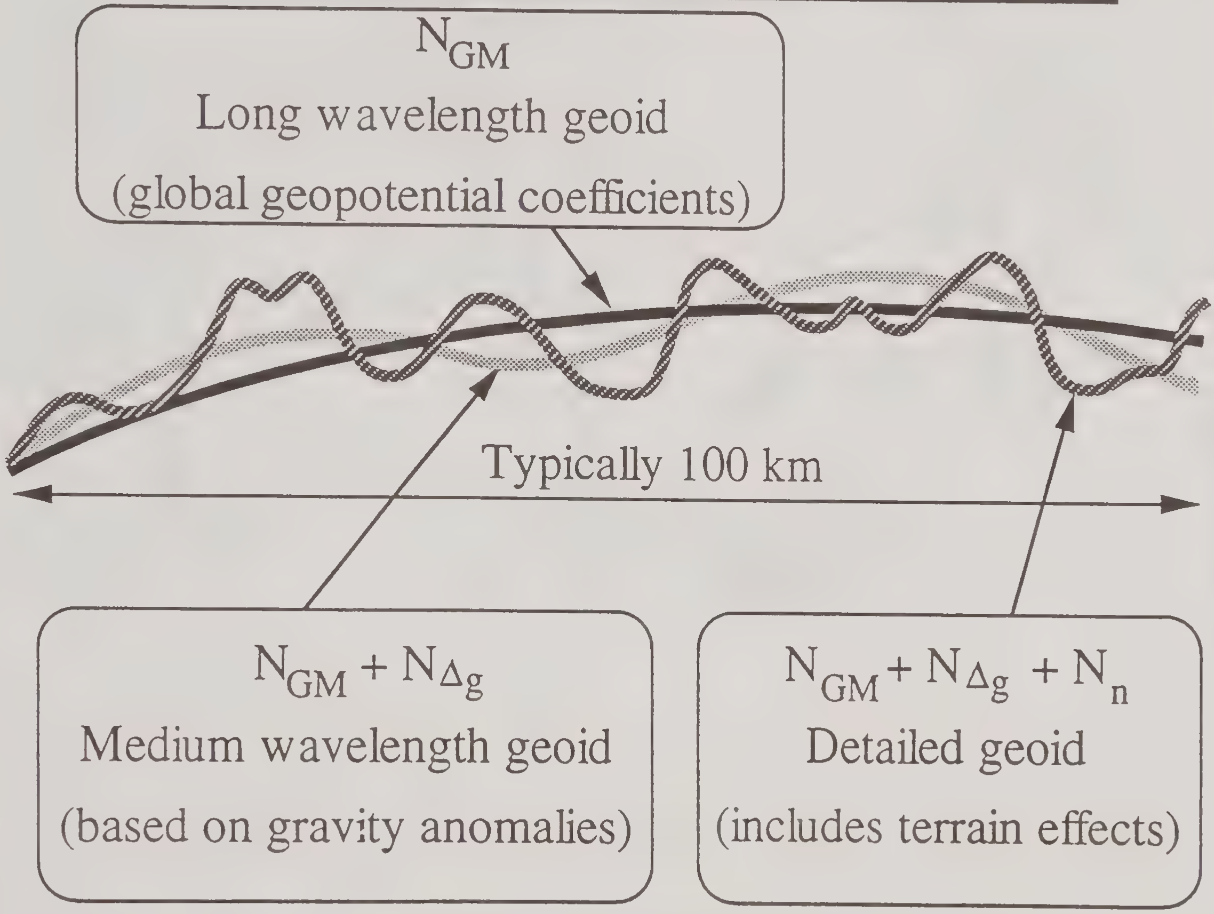
- **WGS84 TO OTHER DATUMS**
  - DMA gives relationship of WGS84 to some 83 datum around the world

[1] Surveying Offshore Canada Lands for Mineral Resource Development, 3rd Edition (1982). Energy, Mines and Resources Canada.

HORIZONTAL AND VERTICAL DATUMS



GEOID ACCURACY



Geoid	Terrain type	Accuracy (1σ)		
		N_{GM}	$N_{GM}+N_{\Delta g}$	$N_{GM}+N_{\Delta g}+N_n$
N (absolute)	Flat	1 m	0.5 m	0.5 m
	Mountainous	2 m	1.5 m	0.7 m
ΔN (relative)	Flat	5-7 ppm	2-3 ppm	2-3 ppm
	Mountainous	7-10 ppm	3-7 ppm	2-3 ppm

GPS ERROR SOURCES

- Satellite Errors:

Orbital:	Nominal:	20 m
	SA:	50-150 m
Clock:		10 m

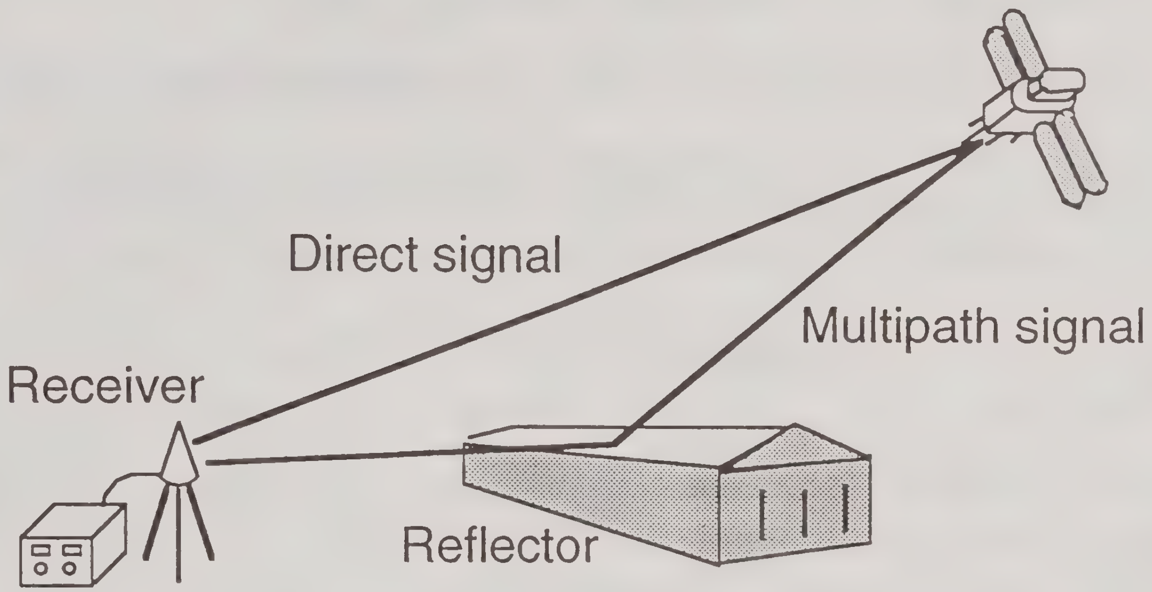
- Propagation Errors:

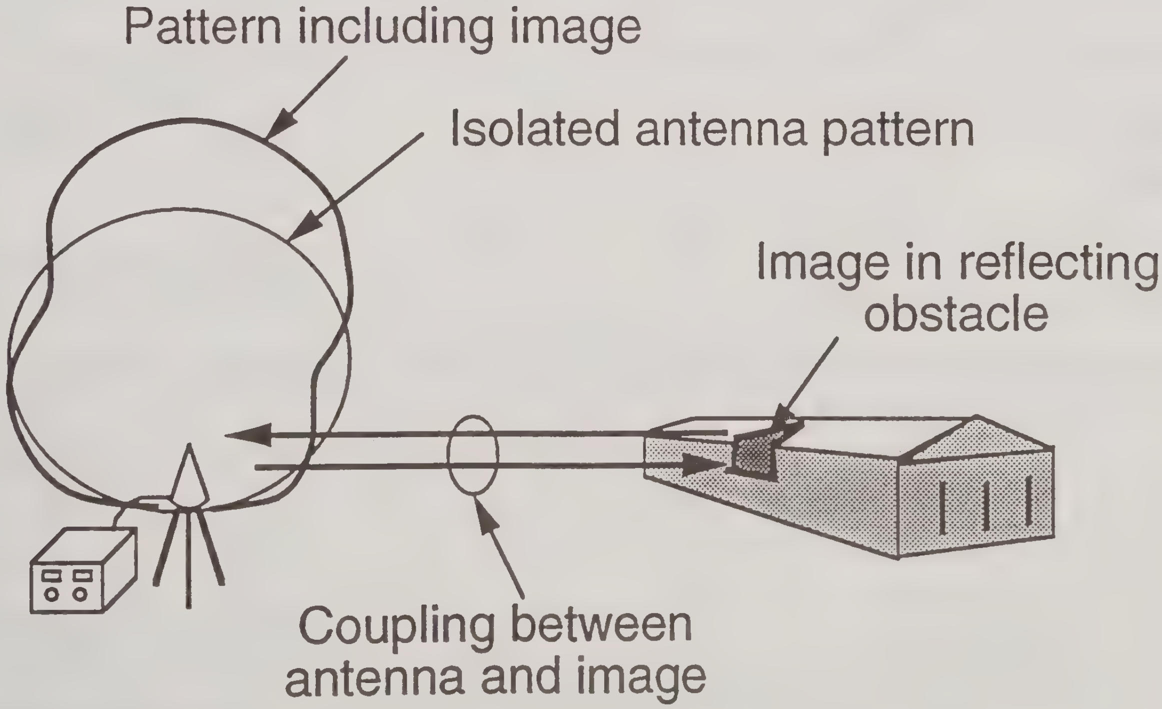
Ionosphere:	2-50 m
Troposphere:	2-30 m

- Receiver Errors:

Multipath:	0.2-3 m
Noise:	0.1-3 m

MULTIPATH AND IMAGING





GROUND MULTIPATH (2/2)

- Dielectic constant, conductivity, index of refraction, and critical elevation angles for various soils
- Reflection (multipath) might occur below these angles
- Sea water is an excellent conductor and much of the incident signal is reflected as opposed to being absorbed by the water - critical elevation is therefore higher

Type of soil and [typical U.S. location]	ϵ Typical Dielectric Constant	σ Typical Conductivity mS/meter	n Real part of Index of Refraction	Critical Elevation, Degrees
Sea Water	81	5000	9.0	83.6
Fresh Water	80	1	8.9	83.6
Pastoral, low hills, rich soil	20	30.3	4.5	77.1
Pastoral, low hills, rich soil	14	10	3.7	74.5
Flat country, marshy, wooded	12	7.5	3.5	73.2
Pastoral, medium hills, forested	13	6	3.6	73.9
Pastoral, medium hills, forested, heavy clay soil	13	5	3.6	73.9
Rock soil, steep hills [e.g., mountainous areas]	13	2	3.6	73.9
Sand, dry, flat coastal areas	10	2	3.2	71.6
Urban residential	5	2	2.2	63.4
Light industrial areas	5	1	2.2	63.4
Heavy industrial areas	3	0.1	1.7	54.7

CLARK, T. (1992) GPS Antennas: De-mystifying Multipath, NASA/GSFC, Greenbelt, MD

WHAT TO DO ABOUT MULTIPATH?

1) SITE SELECTION

- Select site with minimum obstructions
- Roofs are particularly poor
- Watch surrounding medium (e.g. water)

2) ANTENNA SELECTION

- Select antenna which minimizes multipath - low gain at low elevations
- Use groundplane or chokering
- Tradeoff between multipath minimization and tracking capability

3) DETECTION

- Analyse measurement residuals (e.g. plots)
- Day to day residual correlation

4) MODELLING

- Requires modelling of conductivity of surrounding environment - presently not feasible!

US COAST GUARD MARINE DGPS SERVICE

- 50 marine radiobeacons (283 - 325 KHz)
- Range of 60-330 km (land/fresh &sea water)
- Minimum Shift Keying modulation
- RTCM SC-104 (Type 9 message for DGPS corrections)
- Coverage (1996):

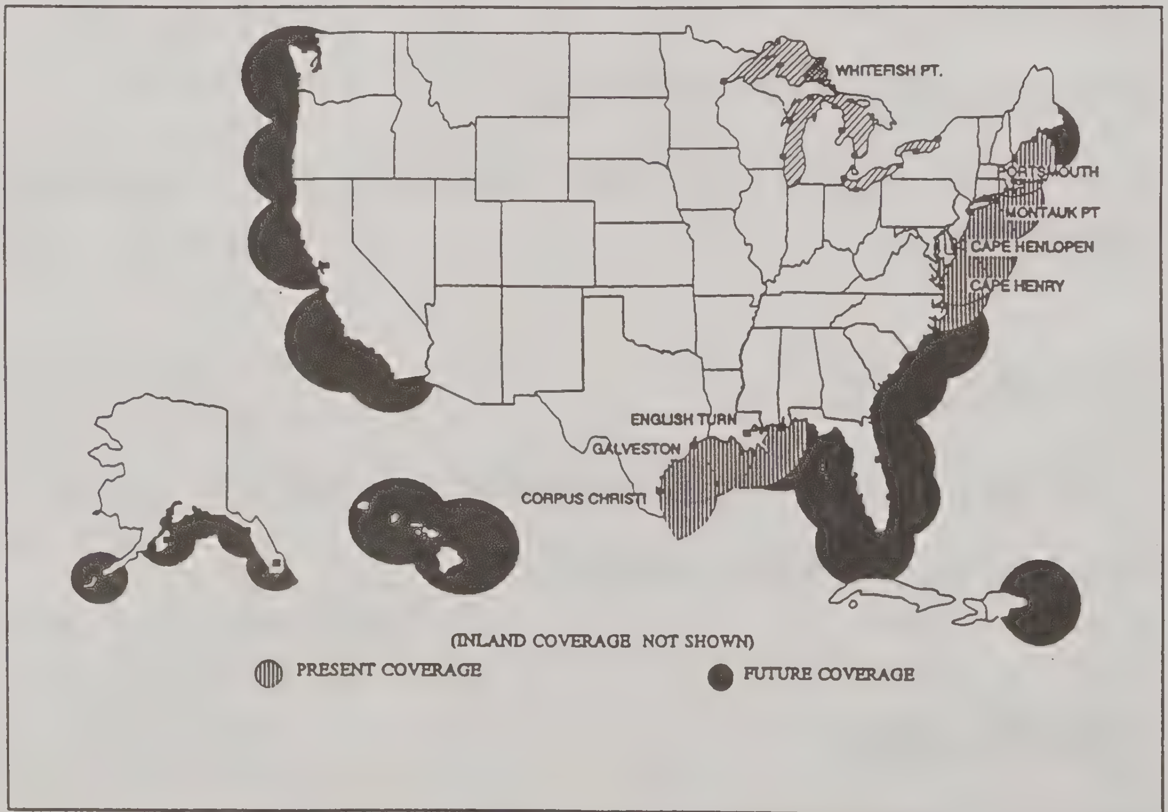
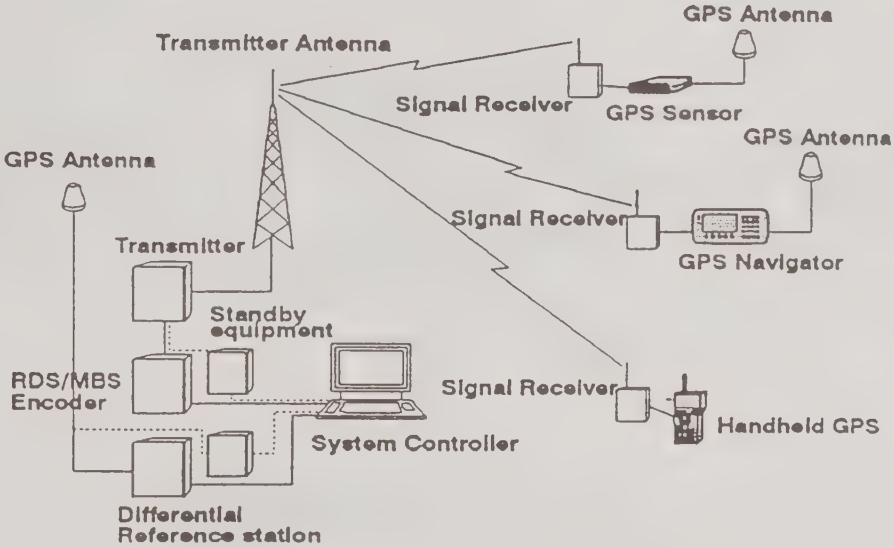


Figure 3 - PROPOSED CONUS, ALASKA & HAWAII DGPS COVERAGE

D. Alsip (1993) Implementation of the U.S. Coast Guard's Differential GPS Navigation Service. Proc. of the 49th Annual Meeting, Inst. of Navigation, Alexandria, VA.

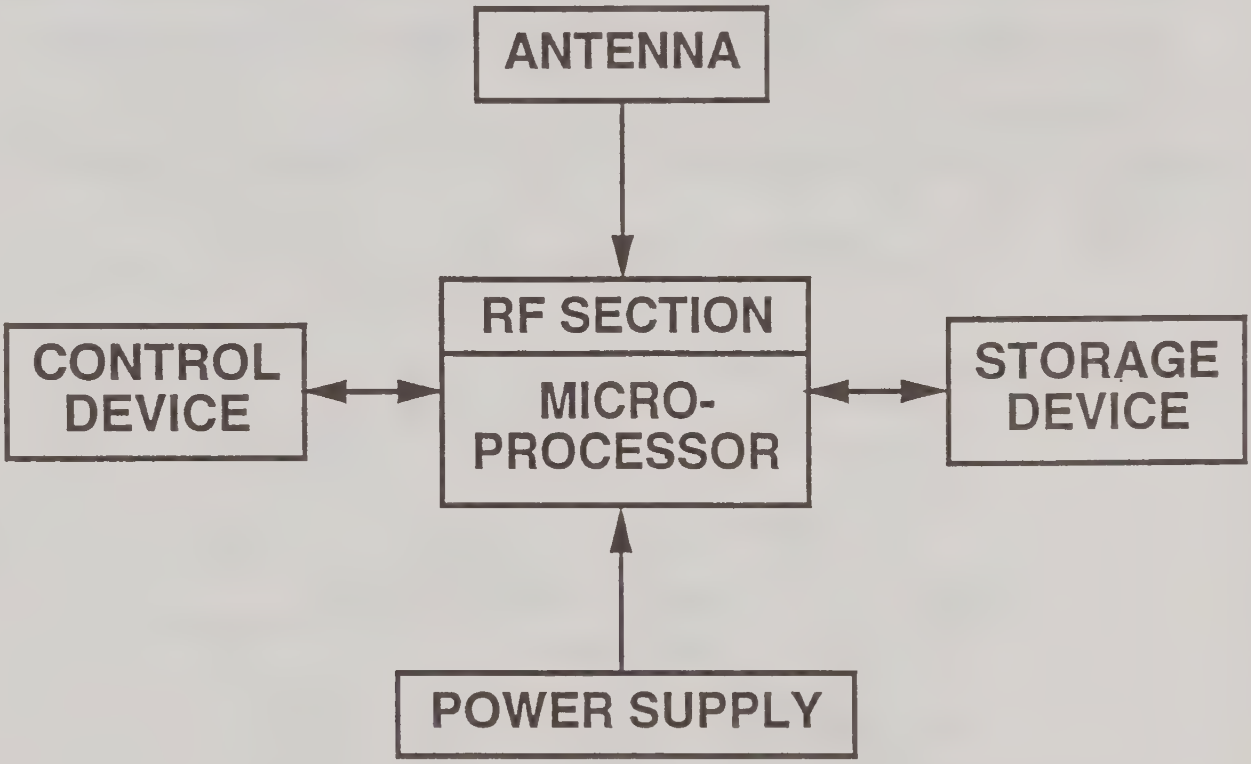
PINPOINT DGPS SERVICE

- US DGPS subsciption service - covers over 90% of the population and 35000 miles of interstate highways
- Transmits RTCM 104 DGPS corrections to users with compact FM data receivers connected to a GPS unit



- Demodulator: $300 Activation fee: $200
  Subscriber fee: $1200 annually (1-5 m); $200 monthly
  $300 annually (20 m); $30 monthly

GPS RECEIVER DESIGN



Antenna:	Receives signals and preamplifies
RF Section:	Delay lock loop and Phase lock loop
Microprocessor:	Controls system and performs real-time navigation
Storage Device:	Used for storing data for post-analysis.
Control Device:	Interactive communication device

Appendix C–Ghent and Allen-Reid Contracting Specifications

DIFFERENTIALLY CORRECTED GLOBAL POSITIONING SYSTEM
SPECIFICATION GUIDELINES
FOR SPRAY AIRCRAFT GUIDANCE AND TRACKING

John Ghent[1] and Debra Allen-Reid[2]

Introduction: How to Use These Guidelines

These guidelines were written in response to requests by gypsy moth suppression program managers for technical assistance in incorporating Differentially Corrected Global Positioning Systems (DGPS) into their aerial spray contracts. The process to develop system solicitation (or contract) language began with a working session held on this subject during the "DGPS Navigation Tests and Demonstration" hosted by the USDA Forest Service Missoula Technology and evelopment Center in September, 1994. Federal (USDA APHIS and Forest Service) and state gypsy moth program managers, industry representatives, and pilots, all contributed to the specification development.

During the discussions and reviews of the specifications, much attention focused on essential vs. desirable features. Because the application of this technology to forest insect suppression is relatively new, we have tried to be specific in our descriptions and perhaps may have included features that are not essential to your operations. For this reason, we are referring to the contents of this document as "guidelines". Any item that does not fit your needs may be omitted. Before adding features not listed, however, check that your specifications do not unfairly exclude competition among potential contractors or systems.

If you opt to format your solicitation as an Invitation for Bid (IFB), the bid will be sealed, there be will no evaluation factors or discussion, and the award will go to the lowest bidder meeting the specifications. The alternative to IFB is the Request for Proposal (RFP), which solicits a negotiated offer, has evaluation factors, allows discussion, and is not necessarily awarded at the lowest price offered.

You may wish to require that your agency be permitted to inspect a proposed system for proper installation and function prior to award (may be added to Item A4, below). If you prefer to do this after award, include a provision to inspect the system a specified number of days prior to the start of the contract and include a penalty clause for delay.

Below is an outline of system functions and specifications. Boldface user notes are not part of the solicitation (or contract) language.

A. Aircraft Guidance

The make of Differentially Corrected Global Positioning System (DGPS) for aircraft guidance and tracking must be specified by the potential contractor in their bid/offer.

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[1]Entomologist, USDA Forest Serv., Southern Region, Forest Health, Asheville, NC
[2]Entomologist, USDA Forest Serv., Northeastern Area, Forest Health Protection, Morgantown, WV

Certain electronic guidance systems may not meet program requirements. Guidance systems that meet the following criteria are acceptable:

1. Differentially Corrected Global Positioning System (DGPS) with software designed for parallel offset in increments equal to the assigned swath width of the application aircraft or the formation of aircrafts. A course deviation indicator (CDI) or a course deviation light bar must be installed as specified in Item C-9. Differential correction may be provided by a portable differential station, FM radio fixed towers, or satellite. Differential correction signal must cover the entire project area.

2. The guidance system being used will allow the flight log to be downloaded to an on-site (airport or helibase) computer for post-flight analysis and review. The flight log must show the entire flight of the aircraft from takeoff to landing and differentiate between spray on and spray off when viewed on the computer monitor. The software must have the capability to zoom to any portion of the flight for viewing in greater detail and a method to determine distance between each flight lane. The system must be able to calculate and show total acres treated during the flight. The software must be compatible with dot matrix printers and/or color printers and differentiate between spray on and spray off on the printed copy.

3. The DGPS proposed must have been operated successfully in a similar type aerial application program, and demonstrated success prior to the last 3 months. Provide name and phone number of previous clients or other users of the system who can validate the DGPS capabilities.

4. Pilot proficiency or evidence of prior experience with the proposed DGPS system must be demonstrated to the soliciting agency prior to award. **[Note to soliciting agency: possible sources of verification include name and phone number of previous clients, pilot's log book, or certified training. A demonstration is also a possibility.]**

B. Electronic Guidance and Support Furnished by the Contractor

The contractor shall provide the following:

1. All guidance equipment, materials, computers, printers, personnel, and services required for the system to be used. The guidance equipment shall be capable of accurately guiding the aircraft, while flying at application altitude, along parallel flight lines equal to the assigned swath width of the application aircraft, in blocks designated by the soliciting agency. The system shall be sufficiently sensitive to provide immediate deviation indications and sufficiently accurate to keep the aircraft on the desired flight path. The guidance system shall be capable of updating current position at a rate of five (5) times per second.

2. FAA certified mechanic/inspector to install and certify equipment installation in aircraft.

3. Differential correction coverage for the complete operation area. During operation, differentially corrected signal must be accurately recorded at least 90% of the operational time.

4. Post-flight processing computer and software capable of displaying track, altitude and groundspeed of aircraft during flight, with differen- tiation between standard flight and flight when the application system is on/off. Export file format must be compatible with ARC-INFO or GRASS GIS systems and must be on a standard High Density 1.44 MB 3.5 inch floppy disk or other mutually acceptable data storage medium.

5. Instruction of soliciting agency personnel in the use of post-processing software. Complete operation manuals.

6. Full 24-hour on-call equipment service and operator support.

7. All related equipment shipping and contractor personnel travel costs.

C. Salient Characteristics Required for the DGPS System

The equipment offered must possess the following features:

1. Precision GPS guidance with pilot-selected cross-track error readout adjustable down to one (1) foot.

2. Easy to operate, user friendly pilot's control keypad, with swath advance and decrement function.

3. Visual display monitor: 1) capable of displaying swath width over flight path; 2) mounted in aircraft in a location that will allow the pilot to view the screen with direct or peripheral vision without looking down; 3) may display in real time or be available for in-flight access immediately after application has ceased.

4. Variable swath width entry.

5. Record logging at a minimum rate of one-second intervals. Full record includes position, time, altitude, speed, track, application system on/off, aircraft number, pilot, job name or number, and differential correction status.

6. System memory capable of storing up to 8 hours of continuous flight log data.

7. Capability to accept pre-loaded reference waypoints (A-B Line). Must be able to store and retrieve, in-cockpit, at least 50 individual treatment blocks, each containing up to 50 points. Capability to link blocks together for combined treatment.

8. Feature which alerts pilot when he/she is about to enter or exit a specific treatment block or an exclusion area within a block. A method to display nested polygons to indicate sensitive, or no-spray areas within treatment blocks.

9. A course deviation indicator (CDI) or light bar which displays both cross-track error and intercept angle to desired heading must be installed on the aircraft in a location that will allow the pilot to view the indicator with direct or peripheral vision without looking down.

10. HOME navigational feature which provides instant range and bearing to home base airport or helibase.

11. MARK feature which allows return to point in any swath before or after equipment shutdown.

12. Warning method to indicate GPS or Differential Correction failures.

13. Pilot-adjustable intensity lighting for light bar, keypad, and moving map display.

14. Capability to end log files, rename, and start new logs in flight.

D. Treatment Site Information Furnished by the Soliciting Agency

Treatment area locations will be provided to the contractor in the following format:

[Note to soliciting agency: Format for how the contractor will input the treatment block coordinates or location into their DGPS may affect the bid/offer price. Below are possible choices that can be used. Other techniques may be available and could be discussed at pre-bid meetings.]

* ARC-INFO or GRASS GIS format files for uploading treatment block coordinates using a WGS84 coordinate standard.

* Outlined treatment blocks on 1:24,000 scale USGS Quadrangle maps. Digitizing responsibility will be by mutual agreement.

* Latitude and Longitude or UTM coordinates of individual spray block boundaries. **[Note to soliciting agency: This could be accomplished with hand held GPS units at block corners.]**

Appendix D–Program Agenda and Attendees List

DGPS NAVIGATION EVALUATION/DEMONSTRATION
MISSOULA, MT

SCHEDULE

October 11 - Tuesday	8:00am-All day	Sign in at Ruby's Reserve Street Inn, Conference Room 400
	9:00am	Editorial session, Interim Report/1994 Spring Spraying GPS Experience - Karl Mierzejewski
	1:00pm	Nime Mile test site visit and bark beetle tour - Tim McConnell
	6:30pm	Dinner

October 12 - Wednesday (flying day-Pestechcon/Agnav)

	7:30am	Welcome
	7:45am	Transportation leaves Ruby's
	8:30am	Aircraft arrive in Nine Mile area for demonstration and test
	11:00am	Transportation leaves Nine Mile to return to Missoula
	11:30am	No host lunch
	1:00-5:00pm	Reconvene at Ruby's Conference Room 400 for demonstration recap and presentation, roundtable discussions
	6:30pm	Dinner, informal at Tim McConnell's home

October 13 - Thursday

8:00am	Introduction by Harold Thistle
8:15am	GPS Overview - Tony Jasumback
9:00am	Transportation leaves Ruby's
9:30am	"Hands on" demonstration at Nine Mile. Survey grade and hand held GPS and differential stations - Don Patterson and Tony Jasumback
11:15am	Transportation leaves Nine Mile to return to Missoula
12 noon	No host lunch
1:15pm	Reconvene at Ruby's Conference Room 400 for Contract Discussion moderated by Tim Roland and John Ghent
2:30pm	Map Data - Bob Adams Computer generated terrain modeling - Deb O'Rourke
3:30pm	Repeater operations - Bob Adams
4:15pm	Other topics - Harold Thistle
6:30pm	Dinner

October 14 - Friday (flying day - Satloc/Custom Farm Service)

7:30am	Welcome
7:45am	Transportation leaves Ruby's
8:30am	Aircraft arrive in Nine Mile area for demonstration and test
11:00am	Transportation leaves Nine Mile to return to Missoula
11:30am	No host lunch
1:00-5:00pm	Reconvene at Ruby's Conference Room 400 for demonstration recap and presentation, roundtable discussions.
6:30pm	Dinner

October 15 - Saturday

	This is a working session moderated by Harold Thistle and held in MTDC's conference room (library). All are invited.
9:00am	New Zealand Perspectives and Experience- Brian Richardson
10:00am	The Future of Spray Drift Modeling in the USDA Forest Service - Jack Barry
11:00am	Project Activities in Spray Drift Modeling at MTDC - Harold Thistle
12:00noon	Portland GPS Presentation - Karl Mierzejewski and Harold Thistle
3:00pm	Picnic at Harold and Gay Thistle's

October 17 - Monday

8:30am	Editorial session, Project Report held in Ruby's Conference Room 400
9:30am	Transportation leaves Ruby's for Stone Container tour
11:30am	Transportation returns to Missoula
12:00noon	No host lunch
1:00pm	Transportation leaves Ruby's for MTDC visit
2:00pm	Transportation leaves MTDC for AFD tour
3:30pm	Fire Lab tour
4:30pm	Transportation returns to Missoula
6:30pm	Dinner

October 18 - Tuesday (flying day-Zycom)

7:30am	Welcome
7:45am	Transportation leaves Ruby's
8:30am	Aircraft arrive in Nine Mile area for demonstration and test
11:00am	Transportation leaves Nine Mile to return to Missoula
11:30am	No host lunch
1:00-5:00pm	Reconvene at Ruby's Conference Room 400 for demonstration recap and presentation, roundtable discussions.

DGPS NAVIGATION EVALUATION/DEMONSTRATION

October 11-14, 1994

Missoula, MT

NAME	COMPANY & ADDRESS	WK NUMBER
Terry L. Biery	910 AG/DOS YARS, Ohio 44473-0910	614-866-8649
Brian Richardson	New Zealand FRI Private Bag 3020 Rotorua, NZ	(07)3475516 E-Mail: RichardB@Tawa.FRI.CRI.NZ
Pat Skyler	USDA Forest Service Forest Pest Management 2121C Second Street Davis, CA 95616	916-758-4600
Dayle Bennett	USDA Forest Service 517 Gold Ave., S.W. Albuquerque, NM 87102	505-842-3190
David Blackburn	Arkansas State Plant Board 1 Natural Resources Drive Little Rock, Arkansas 72015	501-225-1598
Susan Thomas	USDA Forest Service 180 Canfield Street Morgantown, WV 26505	304-285-1632
John Ghent	USDA Forest Service P.O. Box 2680 Asheville, NC 28804	704-257-4328
John McClure	Picodas 100 #6, W. Beaver Cr. Richmond Hill, Ontario L4B 1H4	905-764-3744
Karl Mierzejewski	Penn State University Pesticide Research Lab University Park, PA 16802 E Mail: Karl_Mierzejewski@AGCS.CAS.PSU.EDU	814-865-1021
Darrell Alward	Forest Protection Limited Comp 5, Site 24, RR #1 Fredericton, NB E3B 4X2	506-446-6930
Arthur Robinson	Forestry Canada, FPMI P.O. Box 490, Sault Ste. Marie, Ontario, Canada P6A 5M7	705-949-9461
Amy Onken	USDA Forest Service 180 Canfield St. Morgantown, WV 26505	304-285-1565

Doug Burkett	910 AG/DOS YARS, Ohio 44473-0910	216-392-1111
Karen Felton	USDA Forest Service Forest Health Protection 180 Canfield Street Morgantown, WV 26505	304-285-1556
John R. Omer	USDA Forest Service 180 Canfield Street Morgantown, WV 26505	304-285-1544
Pierre Rouleau	Pestechcon Franklin County Airport R.D. 2, Box 279, Swanton, VT 05488	802-868-7951
K. Neal Snyder	910 AW YARS, Ohio 44473-0910	216-392-1111
Debra Allen-Reid	USDA Forest Service Forest Health Protection 180 Canfield Street Morgantown, WV 26505	304-285-1557
Martin Davis	910 AW YARS, Ohio 44473-0910	216-392-1360
Earl Fullen	Custom Farm Service P.O. Box 338 Stanfield, AZ	602-424-3322
Mary Fullen	Custom Farm Service P.O. Box 338 Stanfield, AZ	602-424-3322
Mike Schiffer	Al's Aerial Spraying 3473 N. Shepardsville Ovid, MI 48866	517-834-5067 FAX: 517-834-5098
A. Temple Bowen	Novo Nordisk 33 Turner Rd. Danbury, CT 06813-1907	203-790-2632
Tim McConnell	USDA Forest Service - FPM P.O. Box 9397 Missoula, MT 59801	406-329-3136
Jeff Witcosky	USDA Forest Service - Forest Health P.O. Box 233 Harrisonburg, VA	703-564-8387
Keith Sprengel	USDA Forest Service - FID P.O. Box 3623 Portland, OR 97208	503-326-6695

Harold Thistle	USDA Forest Service - MTDC Ft. Missoula, Bldg. 1 Missoula, MT 59801	406-329-3981
Dean C. White	TD Comms 1007H - 55 Ave., NE Calgary	403-274-4663
Bob Adams	USDA Forest Service (Retired) 932 Monte Vista Drive West Chester, PA 19380-6030	610-436-5664
Jim Hadfield	Forestry Sciences Lab 1133 N. Western Avenue Wenatchee, WA 98801	509-664-2777
William Frament	USDA Forest Service P.O. Box 640 Durham, NH 03824	603-868-7707
John Anhold	USDA Forest Service Ogden Field Office Ogden, UT	801-476-9732
Roger Menard	USDA Forest Service P.O. 5500 Pineville, LA 71460	318-473-7286
Gary Laudermilch	PA Bureau of Forestry P.O. Box 94 Wellsboro, PA 16901	717-724-2868
Ernest Abel	Michigan Dept. of Agriculture 350 Ottawa NW Grand Rapids, MI 49505 E Mail: AL067.LEO.NMC.EDU	616-456-6988 FAX: 616-456-8850
Ken Slagell	K&K Aircraft, Inc. P.O. Box 7 Bridgewater, VA 22812	703-828-6070 FAX 703-828-4031
Timothy Roland	USDA APHIS PPQ Aircraft & Equipment Operations Rt. 3 Box 1001 Edinburg, TX 78539	210-580-7270
Ray Watson	COMTEL Systems P.O. Box 644 Wanganui, NZ	0064 63454815
Don Judd	Wanganui Aero Work P.O. Box 509 Wanganui, NZ	0064 63453994

Jack Barry	USDA Forest Service 2121C Second Street Davis, CA 95616	916-758-4600
Nick Clemens	Wisconsin Dept. of Agriculture Trade & Consumer Protection 801 Badger Road Madison, WI	608-266-5295
Dennis Haugen	USDA Forest Service - FHP 1992 Folwell Avenue St. Paul, MN 55108	612-649-5248
Ian McDonald	Ace Vegetation Service Box 227 Nisku, Alberta Canada TOC 2GO	403-955-8980
Doug McDonald	McDonald Ranch & Lumber Box 804 Eureka, MT 59917	604-887-3472
William Buzzard	PA Bureau of Forestry, FPM 34 Airport Drive Middletown, PA 17057	717-948-3941
Ralph E. Webb	USDA - ARS Bldg 402, BARC-East Beltsville, MD 20770	301-504-8262
Chuck Dull	USDA Forest Service 14th & Independence Ave. SW Washington, DC	202-205-1416
Kevin McCann	Cartographics 815 E. Front Street Missoula, MT 59802	406-542-1541
Larry Stipe	USDA Forest Service - FPM P.O. Box 7669 Missoula, MT 59801	406-329-3289
B.W. Jorden, Jr.	B. W. Jordan & Co., Inc. P.O. Box 36373 Tucson, AZ 85740	602-297-4017 FAX: 602-297-3490
John L. Goodwin	Custom Farm Service of AZ P.O. Box 338 Stanfield, AZ 85272	602-424-3322
Jason S. Heyn	Custom Farm Service of AZ P.O. Box 338 Stanfield, AZ 85272	602-424-3322

Arthur Escobedo	Custom Farm Service of AZ P.O. Box 338 Stanfield, AZ 85272	602-424-3322
Sam Lagusis	Custom Farm Service of AZ P.O. Box 338 Stanfield, AZ 85272	602-424-3322
Bill Falkenberg	SATLOC, Inc. 4670 S. Ash Avenue Tempe, AZ 85282	602-831-5100

Appendix E–MTDC Aircraft Guidance Project Trip Reports

United States Department of Agriculture | Forest Service | Southern Region

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Reply To: 3400/1390 **Date:** April 20, 1993

Subject: Global Positioning System (GPS)
Aerial Guidance Systems Evaluation Trip Report

To: Director, Forest Pest Management
Thru: Wesley A. Nettleton, Group Leader
Kenneth M. Swain, Deputy Director

I participated in an evaluation of two Global Positioning System (GPS) based aerial guidance sytsems for spray aircraft on February 3-7 in Las Cruces, NM. The evaluation was a cooperative effort with participation by Karl Mierzejewski of Pennsylvania State university, Bill Tanner of APHIS, Harold Thistle, and Tony Jasumback from the Missoula Technology and Development Center. The test was designed to evaluate the precision that flight lines could be flown using these guidance systems. The two GPS systems evaluated gave impressive demonstrations and I believe this new technology is ready for evaluation on large scale operational spray project in the East.

The two GPS systems evaluated were the Picodas Pnav 2001 and the SATLOC AirStar guidance system. The Picodas system was demonstrated by Mr. John McClure and Mr. Pierre Rouleau of PESTECHCON, INC. This system used a real time base station and an onboard differential receiver mounted in the APHIS aircraft that was flown by Bill Tanner. The SATLOC system was demonstrated by Joseph Hartt and John Goodwin. This system was installed in an aircraft belonging to SATLOC and a real time base station was not utilized. Both systems demonstrated the operational utility of this emerging technology. Karl, Bill, and the MTDC folks will be preparing detailed technical reports on the evaluation which I will circulate when they are received.

I will direct my comments to the operational utility I foresee in the use of GPS aerial guidance systems. On many projects the field work force used to mark and flag boundaries could be reduced or eliminated resulting in cost saving and reduced worker exposure. The need for and cost associated with an observation aircraft would also be eliminated. The post flight computer displays and printouts would serve as pay documents and provide a record showing the areas that were sprayed and under what weather conditions. The overall efficiency of the spray operation would be improved by providing precise spray block and base location, resulting in fewer aircraft hours and lower application costs. The major benefit would be in the improved spray coverage and pest suppression. All the features of aerial guidance systems may not be advisable for some of the terrain we work in, but many would be of use.

What is the cost of these systems? Estimates range from $35,000 to $65,000 for a real time GPS base station and an onboard differential receiver in the aircraft. Additional spray aircraft in an area would only require a differential receiver. We need an evaluation to determine if a real time GPS base station is even needed in forestry aerial application work. What precession do we really need? If the signal generated from the satellites is within 10 to 20 meters and varies gradually over time, it may be sufficient for our needs. The software for the two systems have different capabilities and are under continuing development, but both were sufficient to meet our needs. In an operational Plains Cotton Grower's Diapause Program in Texas, 450,000 acres were sprayed with five aircraft using services and equipment contracted from SATLOC. The cost was about 25 cents an acre on this project. I estimate our current field related cost to be $3 to $5 per acre.

Where do we go from here? I do not think FPM should or would want to purchase any systems. I think we need to consider funding a demonstration with one of our contract applicators. This would evaluate cost and utility in our programs. The cost analysis I will be doing this summer should identify field costs that may be eliminated with an aerial guidance system so some comparisons can be made. In our future contracting, we may want to identify aerial guidance systems as an item in the Request for Proposal (RFP) and make allowances to encourage the rapid adoption of this technology by forestry aerial applicators. With our field cost for personnel, vehicles, observation aircraft, and data management I believe this technology would be very cost effective and improve the overall quality of our programs.

/s/ Harold W. Flake

HAROLD W. FLAKE
Aerial Application Specialist

cc: J.Barry:R05A
H.Thistle:R01A
A.Jasumback:R01A
AHPIS, B.Tanner
K.Mierzejewski

MESSAGE SCAN FOR ANTHONY JASUMBACK

To H.Toko
To W.Nettleton
To K.Swain
CC J.Barry:R05A
CC H.Thistle:R01A
CC A.Jasumback:R01A

From: Director, FPM:R8 Host: R08A
Postmark: Apr 20,93 8:57 AM Delivered: Apr 20,93 7:03 AM
Status: Certified
Subject: 3400 Global Positioning System (GPS) Trip Report

---------=========X=========--------

Visit to Potential Automated Sketchmapping System Vendors - Trip Report

March 1-2, 1995

Prepared by:

Harold Thistle - Missoula Technology and Development Center (MTDC)
USDA Forest Service

Vendors and Locations Visited:

ArNav Systems, Inc.
Pierce County Airport
16923 Meridian East
P.O. Box 73730
Puyallup, WA 98373

AvCan Technologies, Inc.
11465 Baynes Road South - #1
Pitt Meadows, BC, Canada V3Y 2B4

Travelers:

Harold Thistle	MTDC	
Tony Jasumback	MTDC	
Tim McConnell	Region 1	FPM

Primary Contacts:

J. Ben Fulton Technical Sales Representative ArNav 206-848-6060

David J. Heukelom V.P. Marketing AvCan 604-465-0907

Objective:

The objective of this trip was to review the state-of-the-art in GPS guided moving map displays used in aircraft which allow direct data input through the map display. The two companies visited had previously been identified as potential suppliers of basic systems. They also have shown some interest in doing problem specific development.

Problem:

Forest Pest Management (FPM) conducts an aerial forest health inventory every season to inventory forest health in the National Forest System. FPM personnel fly over all FS forested land and draw a map (sketch map) showing areas of diseased trees, blowdown and other forest conditions that will be of interest in evaluating forest health. The current procedure involves marking on a paper map in the cockpit and then transferring this data to an electronic database at some later time. Technology is sought that will allow data entry directly into a computerized moving map display in the cockpit thus eliminating the post-flight digitization step. The envisioned procedure would be more convenient and efficient than the existing procedure and would allow easy

transfer of data to an electronic database. Closely related technology is available off-the-shelf but the unique nature of the sketchmapping task will require some development. Tim McConnell of R1 FPM is an experienced sketchmapper and was included in this trip to evaluate system feasibility and to keep the discussion focused on realistic approaches. Tim's thoughts on the trip are appended at the end of the document.

Background:

ArNav Systems is a company known to me through my involvement with DGPS guidance systems for spray aircraft. At a demonstration in Glendale, AZ in August, I had talked to Sue Hammer (V.P. Marketing - ArNav) about adapting an existing ArNav system used in wildlife tracking to the sketchmapping problem.

AvCan Technologies is a company that I became aware of at the National Agricultural Aviation Association Annual Meeting in Las Vegas, NV (Dec., 1995). I gave a talk regarding our DGPS aircraft guidance work and David Heukelom approached me after the talk and we discussed the AvCan product line. I thought the company was worth a closer look at that time.

Activity:

Tony, Tim and I arrived at ArNav Systems which is on the grounds of the Pierce County Airport in Puyallup at about 9:45 a.m., March 1. ArNav had planned a demo and there were between 10 and 15 people in attendance at any given time. Observers included folks from Honeywell, the FBI, the state of Washington, DOD and a group from an emergency medical helicopter company.

The primary focus of the demo was the ArNav System 6. This system is a multi-vehicle tracking system which I have reported on previously. The system allows tracking of multiple vehicles, both ground and air by a single operator. The system software is quite sophisticated so that vehicles in the system are polled regularly, each individual vehicle will automatically become a repeater for another shadowed vehicle when necessary and various triggers (based on location, engine parameters, vehicle speed etc.) can be used to cause a vehicle to 'shout' back to the tracker if a flagged situation occurs between the normal polling events. It is difficult for me to summarize the full extent of this system and I will refer the reader to the ArNav commercial literature. The ArNav 6 system requires each vehicle to carry a 'black box' which is a GPS receiver and a transmitter. The systems can be made to be differential through the insertion of a card and availability of differential correction. The system is installed at Denver International Airport where it is used for ground vehicle tracking. The system was presented in detail and a demonstration was set-up where the system successfully tracked two planes and a car simultaneously. The only real question I had about the system concerned the update rate. The update rate can be made specific to the application but the on screen map seemed to be updating about every twelve seconds while the stated update rate was every two seconds.

During the day, we talked at some length with Bob Brooks (Senior Sales Engineer, ArNav) about the sketchmapping problem. Bob is a former retardant tanker pilot and has a good feel for FS applications. ArNav has an existing system which is used to put out medicated food near wildlife at high risk of rabies. This is an airborne system which allows input of animal type onto a moving map display and records the amount of food dropped and the exact location of the drop. This system performs many of the functions of the desired sketchmapping system. I was somewhat frustrated with ArNav in that,

eventhough they had been told in detail what we needed, the focus of this demo was somewhat off-target with regard to the sketchmapping application. Nonetheless, the System 6 multi-vehicle tracking system is very impressive and should have wide potential for application in the FS. We were able to talk at some length about sketchmapping and ArNav does have an off-the-shelf approach which shows promise.

The following day (March 2) we arrived at AvCan, Technologies in Pitt Meadows, BC. AvCan is a relatively small company (12 employees) and their focus is in moving map displays and synchronized video. This group came across as very innovative and energetic. They began by giving us a basic demonstration of a system they call VidTracker. This is a DGPS synchronized video and moving map display which allows you to replay a video taken during a flight while observing the flight path on a GIS on an adjacent screen. This is quite an impressive system and I will again leave the detailed specs to the AvCan marketing literature. The demonstration was conducted by Reg Moen (President - AvCan). We emphasized that we did not need the video in this application but we were very impressed by their moving map display. It would be possible using this equipment to read in the DEMs which you were scheduled to fly into the computer and have the quad you were over show on the screen. The map would scroll as you flew and you could input via a mouse/cursor onto the screen. The presentation on the screen would almost exactly duplicate a paper topo map with the additional ability of being able to zoom in and out (variable scale). Tim was concerned that he be able to add text attributes (basically notes regarding tree type, diagnoses, etc.). This is not a problem, though we need to check the time lag on this feature. This moving map display and the related hardware/software provides a near off-the-shelf solution to the sketchmapping problem.

Reg Moen then gave us a demonstration of the AvCan system they call AgTracker in an instrumented company van. This is the system which AvCan markets into the agricultural spraying market for precision vehicle guidance. All of the systems demonstrated by AvCan used differential corrections. One feature which impressed us regarding the AvCan systems is that they have developed an innovative approach to the 'contour flying' problem. We have previously stated that it might be very useful to give curved line guidance in FS application due to the necessity of flying contours in mountainous spray applications. This is a difficult problem due to pilot lead time, workload and general safety concerns. The system developed by AvCan presents an idealized irregular flight path so the pilot knows what is ahead. As he moves along the curvy path, the system displays a straightline tangent to the curve at his current position and the right-left off track. This appears to be a simple, promising approach to a difficult problem and should be investigated further as a possible to solution to preprogrammed guidance of a spray aircraft in mountainous terrain.

Actions:

1) Evaluate the project budget and thereby the level of effort.

2) Design a funded test/demonstration of an automated, electronic sketchmapping system.

3) Evaluate system integration into operational FS GIS (615?).

Thoughts from the March 1,2, 1995 Meetings with ARNAV and AVCAN
by Tim McConnell March 6, 1995

ELECTRONIC MAP LAYER

Figure out where to obtain a digital map layer suitable for aerial sketch mapping techniques.

Explore different digital maps for applicability for sketch mapping.

The Kootenai NF forest map is in digital form.
Check with Don Van Nice (R-1, ENG) for availability and compatibility with potential vendors equipment and software.
Figure out what layers are available and can be included.
Determine which layers work best for sketch mapping.

See demo of the 4 quads of DEM digital map that MTDC has in its possession. Check it for suitability, file size, compatibility.

Get more info on rolling screen compatibility for digital maps.

Need for speed in attributing electronically (call up menus could take too much time).

Explore digital map file compatibility with various vendors.

MAPPING

Figure out pixel (point) versus multi-point (polygon). When is it necessary to do more than a point.

Figure out scale appropriate for onboard screen and distance away from from aircraft (space) on onboard screen.

Consider developing a more simple attributing system. Speed of attributing important. Lump 1-5, 5-10, 10-20, 20-50 etc.

Supply vendors with samples of sketch maps to show level of detail.

OTHER COMMENTS

AVCAN seems best suited for a sketch mapping application.

ARNAV seems very well suited for an air attack application.

I feel that at this time the GPS supported digital map system would only improve time processing to a GIS layer or file, no system as yet demonstrates the ability to improve the detection, spatial error or attribute error of general sketchmapping. The available digital map to be used on screen in the cockpit is the key to improved quality.

The aerial survey flight, flying cardinal directions, can be improved using the AVCAN system as is already developed.

ARNAV System Demonstration - Phoenix, AZ

August 24-25, 1994

Prepared by: Harold Thistle

Objective

The purpose of this trip was to attend an equipment demonstration which was jointly sponsored by Honeywell Inc. and ARNAV Systems, Inc. The system being demonstrated is a multiple vehicle tracking system which includes a GIS type display of vehicle position.

Activity

At 9:30 AM on the morning of August 25, 1994 I attended a meeting at Honeywell - Commercial Flight Systems Group in Phoenix, AZ. There were approximately 12 people in attendance. The primary organizers were Fred Weber and Bill Deakyne of Honeywell and Bob Brooks and Sue Hammer of ARNAV. The session began with an introduction to the ARNAV System 6 GPS based multiple vehicle location system. This system is currently in use with various air and ground fleets (examples of operational systems included Denver International, a LifeFlight hospital based ambulance helicopter fleet in the MidWest and an helicopter fleet in the Gulf of Mexico used to service oil rigs).

At 1:00 PM, the demonstration began with two cars dispatched and two aircraft doing flybys. The vehicles could be observed out the window and simultaneously tracked on a GIS type overlay on the computer screen. I also received a demonstration of a moving map GIS display which had been designed to do wildlife inventories in Ontario.

At 2:30 PM, we reconvened in the meeting room and Bob Brooks went into the technical details of how the system worked. The most impressive part of this system from my standpoint were the methods used to detect that a vehicle was not reporting and the method used to find vehicles entering the 'domain'. In the case of vehicles which don't report, the system in the vehicle realizes that it has not been queried for a specified period and then automatically transmits to another vehicle that it can 'see'. The location report is then appended on to the other vehicles report. Therefore, every vehicle can be a repeater at any time. In the case of a vehicle that has just entered the system domain, there is a shout call that alerts the system to its presence and it is then queried regularly after that.

Discussion

Over the course of the day, I was able to have direct discussion with both Bob Brooks and Sue Hammer. Apparently, ARNAV has been extensively involved in the ag aircraft guidance business

for a long time but they could not make our October tests due to schedule conflicts. It certainly is apparent that this company has substantial expertise in this field. The demonstration would be directly relevant to FPM operations where multiple aircraft were operating.

The most directly relevant part of the demonstration for me was a unit shown to me by Sue Hammer. It had been designed to do wildlife inventory work in support of a study on rabies conducted in Ontario. The system utilized a moving map display and allowed the operator to enter data directly into the device during flight. This data was then place time registered based upon the GPS location signal from the aircraft. It is a very close application to that discussed with respect to FPM sketchmapping.

Another important discussion was a 'back of the napkin' summary I obtained from Bob Brooks with respect to fire fighting operations. ARNAV designed a multiple vehicle/personnel positioning and communication system for Environment Canada for use in fire fighting operations in Canada. This system uses a top-cover concept. As soon as some threshold level of fire activity is reached, a high altitude aircraft is dispatched to act as a repeater. A second aircraft is deployed as a mobile command center and all ground vehicles and aircraft (foot personnel as well if necessary) with transmitters are tracked. The mobile command center would include a GIS based computer display with the positions of all units displayed. This information could be transmitted back to the ground for use away from the fire or dispatch and decion making could be run from the mobile unit or both. This top-cover concept means that units will not be obscured by terrain. Bob Brooks is a former retardant pilot and has substantial knowledge and insight regarding fire fighting.

Actions

It is my recommendation that two actions should follow out of this demonstration:

1) It would be worthwhile for MTDC and FPM personnel to sit down with ARNAV and discuss possibilities for the wildlife tracking unit in the sketchmapping application. I do not believe that ARNAV is the only company holding this technology but they certainly demonstrated substantial expertise and have built similiar systems.

2) It would be worthwhile for MTDC and Fire personnel to sit down with ARNAV and Bob Brooks and discuss the technology that he has implemented in Canada. I am not familiar with Fire efforts in this field but Bob's combination of experience in designing this type of system and his experience in fire operations make him a very interesting person to listen to with respect to this type of application.

TRIP REPORT- PHOENIX / NIAGARA FALLS

SatLoc of Casa Grande,AZ held an equipment seminar March 16 and 17 at Williams AFB southeast of Phoenix. The presentation began at 8AM on both days and lasted until 5PM on Thursday. On Friday, in the afternoon, they turned a GPS equipped van over to the students for some "hands on" training.

SatLoc introduced their "Foreststar" parallel swath guidance system during the course. In actuality it is the same system as their "Airstar" as far as I could tell. There didn't appear to be any real difference between the systems other than the name.

Their course was very comprehensive with five or six personnel being involved with the presentation, including engineers and programmers. Two films

were shown, and all components of the system discussed at length. A video camera was used to project the image of the navigation display and control key pad onto a large screen at the front of the class room.

Using this, they ran the students through a series of simulated system checks and operational setups. The program menu was covered in detail. And all operational considerations such as A-B line, and polygon construction discussed. A good bit of time was also devoted to trouble shooting.

On Friday morning they covered their Mapstar digital base mapping system, and map conversion program.

Pestechcon-Agnav's training program was held on March 23 and 24 in Niagara Falls, NY. They recommended that participants bring a lap top or other DOS based pc. Most people that attended

did so.

The Pestechcon presentation covered the same operational areas as SatLoc's. The instruction started at 1PM on Thursday and continued until 5PM. The Friday instruction began at 8AM and continued until 11PM. The participants were then transported by bus to Picodas' assembly facility near Toronto, Quebec, Canada.

Pierre Rouleau conducted the classroom instruction. He utilized a training program that was loaded into each participant's computer, and an overhead projector in his presentation.

Again the course was very comprehensive, covering all components of the system, the installation and setup, and the operational considerations such as polygon and A-B line creation. Pierre also covered digitizing and UTM and GIS and State Plane coordinate conversion.

In Toronto, engineering and programming personnel continued the program. They described the equipment in detail and discussed "in the field" trouble shooting.
Picodas also presented their P111. This is the same as the P101 pc unit, but with improved weather resistant packaging, and military type cable connectors.

These sessions were both a direct result of the round table discussions held during the DGPS Aircraft Demonstration in Missoula in October. The need for more customer support, and the need for government FPM personnel to be more informed about the DGPS systems their contractors would employ on spray projects, prompted these companies to create these training sessions. They were designed for government personnel, and approximately 20 state and Federal individuals attended each session.

There was a lot of information put out in both classes. Both companies did a good job in their instruction. FPM personnel who attended were able to acquire a good working knowledge of the DGPS systems that their contractors would be employing during the coming spray season.

It appears that both firms intend to continue offering these classes. They are definitely worthwhile. They will help in the introduction of DGPS in FPM operations, and alleviate many of the problems encountered in 1994.

Bill Kilroy

To: Dave Rising 11/22/91

I attended the demonstration of SATLOC's GPS guidance system for spray aircraft in Stanfield, AZ on 11/20/91. Present for the demo were:

- Joe Hart, SATLOCK Inc
- Dr.Frank Bletzacker, SATLOC Inc.
- John Kennedy, Kennedy Consultants, Consultant to USDA, Laurel, MD.
- John Morley, Kennedy Consultants
- Sidney Swanson, PATHCOR Inc.
- John Goodwin, Custom Farm Services, Stanfield AZ.
- Billy Tanner, pilot, USDA-APHIS-PPQ
- Tim Roland, pilot, USDA-APHIS

The equipment demonstrated was a developmental prototype and did not include the real time differential GPS capabality or the Inertial Navigation System (INS) for aiding in the turning maneuver at the end of the swath. Both of these are being worked on and planned for the production unit. The system consisted of a c/a code and phase tracking GPS receiver, a control display unit,a modified three element antenna, and a light bar mounted in a Cessna 206. The actual flight demonstration did not turn out to well because selective availability (SA) was on and without real time differential to correct for this, errors of many meters were in the guidance information output to the pilot.

This demo should NOT detract from the system as planned, similar systems being used in kinematic surveying are obtaining submeter accuracy. Granted there are differances such as ground vehicle vs aircraft, post processing differential vs real time differential, and in both cases the receiver must not lose phase lock (loss of signal). The biggest problem is loss of signal which will most likely occur during the radical aircraft maneuver at the end of each swath, in row crop type spraying. This maneuver need not be so radical in forest type spraying and they are developing a three element antenna to help over come this problem. This antenna would normally be mounted on the highest point on the aircraft. One element would be horizontal for use during level flight, the other two would be mounted one on each side and angled 45 degrees to the horizontal one for use during the maneuver at the end of the swath. This antenna arrangement will hopefully eleminate signal loss during these maneuvers.

The INS is intended to provide a faster update rate to the light bar to better assist the pilot in lining up on the next swath after the radical end of swath maneuver. The INS will provide guidance information to the light bar ten times a second while the GPS would provide it only once a second. This was felt to be a must by the pilot's for row crop applications but may not be critical for forestry applications. The INS adds another $10,000 to the cost of the system.

To prevent change of satellites during the spray mission both the base station and the aircraft receiver will be locked onto the four satellites with the best PDOP. This will prevent the potential jump in position some times found with a change in satellites, also it will reduce the amount of data that must be handled by the real time differential communications system. When the PDOP for the current set of satellites becomes to large and another set offers a lower PDOP, the receivers will be locked to the new set while the aircraft is being reloaded.

Recommend FPM continue to monitor this development because it appears to be on the right track for development of a guidance\recording system for aerial applications within the Forest Service. It offers a system more viable than anything we've seen so far. The developement of the first pre-production model is expected by next spring at a cost of under $40,000 per unit.

Tony Jasumback

Las Cruces Trip Report

Dates of Travel: February 3-5, 1993

Destination: Las Cruces, New Mexico

Purpose: To participate in a test of GPS based aerial guidance systems.

Persons Contacted:

Karl Mierzejewski	Penn St.
John McClure	Picodas Group, Inc.
Harold Flake	USFS
Bill Tanner	APHIS

Tony Jasumback and Harold Thistle went to Las Cruces to participate in an instrument demonstration involving Penn St., APHIS, Picodas Group, Inc and the FS. The system being tested while we were present was the Picodas PNAV 2001 which uses a NovAtel GPS 'engine' as its controller. The test was based out of the second floor of a building overlooking the runway at Las Cruces Airport. The Picodas receiver and real time base station setup is shown in Photo 1 with the on-board differential receiver and display setup shown in Photo 2. The Cessna 205 test aircraft is shown in Photo 3 and the tail mounted on-board GPS receiver antenna is shown in Photo 4.

The test itself was designed to evaluate the precision with which a pilot armed only with the guidance system could repeat a line of flight. The flights were performed over flat rangeland near the airport (Photo 5). For the first set of passes, flagmen on the ground indicated the line of flight (Photo 6). These flight lines were logged into the navigation system on board the aircraft. The pilot then attempted to fly these flight lines again using the coordinates which had been stored in the system as indicated by a centerline indicator mounted on the dash of the aircraft (Photo 7). The ground people compiled data on the proximity of the pilot to the actual lines during the second runs. The compiled results indicated that the pilot could regularly repeat the line within 3m using only the stored data (the majority of the time the pilot appeared to be within the observers ability to estimate offline distance, approximately 0-2m). This was a very impressive performance since the landscape had little in the way of landmarks and the ground people were intentionally hiding or standing in the wrong positions trying to confound the pilot.

A second less structured test took place after the line repetition trials. Of interest to many of the participants is the question of performance in complex terrain. The airplane was flown into the nearby mountains (base to peak elevation around 1300m, Photo 8) and the percentage of signal loss monitored. This fixed

wing aircraft could not be flown as close to the surface as a spray helicopter, nonetheless, the performance of this system appeared to be good in terrain typical of that which the FS sprays in the western US.

At the airport, equipment performance was evaluated and John McClure of Picodas gave us an extensive description and demonstration of this system. The electronically logged flight paths can be displayed graphically in various formats on the computer screen and a digitizer pad can be used to click in actual map positions and features so a GIS format can be implemented. That is to say, flight paths can be plotted over actual map features. A limitation of this type of system is the reconciliation of local coordinates and global coordinates. However, when local coordinates are acceptable, this could be a very powerful tool to check spray coverage or to answer legal questions. Eventually, the electronic position files could be used as source coordinate inputs to dispersion models. Note that this system can be interfaced with spray on/off switching and with flow controllers so that emission rate and spray on/off can be monitored, logged and even controlled through this system.
Mr. McClure stated that the irregular flight paths typical of spraying in complex terrain would preclude use of some of the Picodas software features, these problems may have to be overcome before FS can use this system operationally.

Discussion and Recommendations

Various discussions were conducted with the participants at and subsequent to these tests. The results of the tests were generally impressive. It is thought that the technology is far enough along that the FS should begin placing the units in spray aircraft on an experimental basis. Picodas is not the only supplier of this type of equipment. Satloc is another company which builds similiar systems. Satloc demonstrated a system after MTDC had left Las Cruces. According to Bill Tanner of APHIS, the development of the Satloc system appeared to be further along than that of the Picodas system. Harold Flake of Region 8 also participated in these tests and he raised the possibility of including this type of system on future spray trials in the southeast.

Acknowledgements

MTDC would like to acknowledge the work of Karl Mierzejewski of the PSU Aerial Application Technology Laboratory in organizing and implememting this test program.

cc: Jack Barry
Harold Flake
Ben Lowman
Karl Mierzejewski
Dave Rising

Appendix F–Summary of Saturday General Technical Sessions

Jack Barry, Saturday, Oct. 15, 1994, Missoula, MT.

Overview/History of FSCBG

We feel a need to transfer this model technology to sister agencies and cooperators.

What is FSCBG? It's a file of information that has been gathered over the years - but it needs to be much more user friendly and inviting. We're still working on more user friendly, impacting graphics.

Model development to date has been more for the scientist (see attached article by Ann Kalosh - "Bringing Science Down to Earth: An Interview with Carl Sagan").

Model originally came from the U.S. Army - a gaussian plume model.

Designed for long-range drift and elevated line source. FS first used the model in 1971 to predict drift of Zectran spray on Nez Perce NF.

A lot of validation done, here and in New Zealand and still ongoing. Many publications, reports, and meetings.

Model will be used to plan different ways to potentially spray an elk habitat on Lolo National Forest to obtain the best efficacy and safely apply the herbicide. Ed Monnig, Region 1, is the contact.

Future of Model

Connect a simple version of FSCBG to generic GPS system.

Discrete deposition receptors in canopies.

Looking at right wing/left wing vortices - differences have been reported by Bob Mickle.

Enhance model for dry particle dispersion predictions.

Sidewash studies for helicopters - data has been generated through cooperative tests with the U.S. Army. Milt Teske, CDI, is analyzing the data.

A user friendly demo package of the model is being developed.

Deposition/contour pattern - relates to flying contours instead of straight line.

GIS/map overlay will be integrated.

Improvements needed in deposition model so it is more sensitive to aircraft speed and weight.

Gypses - building a decision support system.

Time of day study - looking at effect on deposition and drift at different times of day, as meteorological conditions change.

Plan to do model runs to look at sensitivity of model in more depth and generate a notebook that will answer various questions without the need to run the model.

Hope to build drop tower at UCD to support atomization, non-target impact, sampler efficiency, and spread factor studies.

Model not deficient because it takes drift to infinity. This is a fact of life. We are waiting for biological scientists to tell us dose response so we can then work this information into model and cut drift off at appropriate point downwind.

Bill Jordan - There appears to be a need to hook real-time instruments to model. I need to know what to measure, what quantity to measure (mass?).

Jack Barry - Need to measure mass or volume with ai. Shy away from particle measurement.

Ralph Webb - Should we really be ignoring particle size?

Harold Thistle - The model doesn't ignore particle size.

Jack Barry - Suggested Bill Jordan needs to look at measuring mass/volume first then tackle particle size measurement.

Brian Richardson - Saturday, Oct. 15, 1994, Missoula, MT

Slide presentation which gave an introduction to New Zealand and Forest Research Institute located in Rotorua (center of northern island).

New Zealand - 27 million hectares.

6 million is forested - largest proportion is in native forest, dense undergrowth.

1.2 million hectares in plantation forests (radiati pine)

In New Zealand really talking about farming when they talk about forestry as the forests are managed like farms.

Management Process Used - Most trees come from intensive genetic program. Grown in nursery for 1 year. Prior to planting, site preparation may involve herbicides. They don't use burning.

Planted 800 stems per hectare. Thinned to 250/350 stems per hectare. Harvest in 25-30 years. Some trees exported, preserved/treated, used for building/paneling, furniture, paper.

Why Manage Vegetation?

- Plant removal (non-crop)

    - Gorse - worse weed species in New Zealand (non-native species).

    - Removal - main reason is to remove competing vegetation (for water/nutrients).

    - Developing models of competition so they can predict effects different species have on radiata pine.

- Plant additions (non-crop)

    - Sites may be aerially seeded with grasses/legumes to develop a stand's cover. May stop some of the windblown woody species which are harder to control. Also provides grazing for animals. Provides cover on slopes to decrease erosion. Legumes also add nitrogen to sites (especially sandy sites).

Bottom line - chemicals still most important weed control in New Zealand.

Aerial Application still most important way to apply herbicides in New Zealand. Most sites will receive pre-plant (aerial) and post-plant (spot) applications).

Dose is most important factor of formulation. Lane separation is most important application parameter.

Modeling the effects of deposit variation on crop growth.

Application
Deposition distribution
Effects on weeds
Effects on crops

They have found:

Mean CV = 43%

Range CV = 20-70%

18% of area receives +/- 10% of application rate

they have done tests on flying accuracy using various aircraft. Variation of results demonstrates why they are interested in Global Positioning Systems.

Looking to determine - what is the effect of coefficient of variation on crop growth?

Studying Drift - The experimental approach (trials).

High Costs
Replication difficult

Above are the main reasons they became involved with spray drift models (1990) - FSCBG.

They now have an FSCBG user group in New Zealand.

First they did several validation exercises. Results were very encouraging.

Did their own sensitivity analysis and came up with a series of recommendations on how to minimize drift.

Uses of spray models in New Zealand. General recommendations, buffer zones, operational planning, training, regulatory.

There is still a need to link drift with biological effects - feel a major step still needed with model. It predicts drift for downwind but what are the biological effects at what levels?

Brian demonstrated their Decision Support System for Weed Control Model (Ver. 1.5). Currently DOS based but coming out with a Windows version. Two phases - expert and user interface. Will eventually be interfaced with a GIS system.

Jeff Witcosky - Saturday, Oct. 15, 1994, Missoula, MT.

Was asked by Forest Service to submit a proposal for a hardwood canopy library.

Worked with Dave Miller. Used Licor for measurements at 2 meter intervals to obtain canopy profiles.

Spent two summers traveling NE area sampling forests: Boreal Forests, Northern Hardwood, Upland Oak Types, Bottomland/hardwood types.

Eventually will create a data base library for inclusion in FSCBG.

Other canopies (ie cotton) could be likewise measured and entered into a data base.

Jack Barry wants to pursue Jeff's proposal through IPM/Davis. Jeff is to send Jack a DG message regarding this. Jack sent Jeff the grant proposal forms.

Ralph Webb, Saturday, Oct. 15, 1994, Missoula, MT.

Aim - to develop decision support system for gypsy moth development.

Interested in drift as a cost effective method.

Picked up from this DGPS project:

1. Accuracy applying pesticides - most important factor.

2. FSCBG model

Regarding the experiment he has designed - he will send us his notes once he gets them written up.

John Goodwin, Saturday, Oct. 15, 1994, Missoula, MT.

Things to do on the fly for areas needing variable applications, to work within the short windows we often have to work within:

Rate changes (involves flow meter)

Additional chemicals (i.e. internal tank system)

Droplet size change (new design for nozzles)

Bill Jordan, Saturday, Oct. 15, 1994, Missoula, MT.

Why detect if drift is present? Objective is affordable, real time data.

Conductivity sensor (simple, easy, cheap) - 10 prototypes built. For the applicator - provides real time information through audio beeper/radio which tells pilot drift has been detected.

Harold Thistle - Saturday, Oct. 15, 1994, Missoula, MT

Spray Dispersion Modeling System

Alarm	FSCBG
	Near Field Lagrangian/Source Model
Screen	
	Far Field Gaussian Drift Model
Operation	
	Canopy Penetration Model
Detailed	
	Droplet Evaporation
	Adding
	Complex Terrain

Gaussian $'00's Millions/yr

Pros

Good correlation? (Intuitive)
Predicts maxima
Simple
Repeatable (analytical)
Regulatory inertia
Computationally reasonable
Not chaotic

Cons

Simple
Statistical (not much physics)
No insight
Time evolution
(secondary pollutants)
Not chaotic